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MODELS OF THE PHYSICAL UNIVERSE[1]

By Professor RICHARD C. TOLMAN

CALIFORNIA INSTITUTE OF TECHNOLOGY

INTRODUCTION

FIRST of all, I wish to express my thanks to Professor Boodin and to Professor Miller for suggesting that the Philosophical Union might be interested in some of the recent work of theoretical physicists in the field of cosmology. More than two thousand years ago, at the instigation of Aristotle, scientific expeditions were financed by Alexander the Great to explore the countries which he had conquered and report their findings to the great philosopher and his school[2]; and in coming as a scientist to report to you—who are philosophers—I feel that I am acting in accordance with an honorable and desirable tradition.

Nevertheless, certain changes have occurred in the relations between science and philosophy since the golden time of Aristotle which must not be overlooked.

In the first place, philosophy and science are no longer a united study, and it is not the philosophers but the scientists themselves who now organize and direct their own explorations. Indeed, I think it would have been an unhappy day for science if Galileo had not broken from the Aristotelian tradition, and in any case, whether for better or worse, science has long since issued a declaration of independence from philosophy which can not now be disregarded.

In the second place, the developments of philosophy and science have in the meantime been so extensive and complicated that both disciplines and even their separate branches have been forced to invent special technical languages for the discussion of their subject-matters. Indeed, I have heard a humorous, and I trust untrue, definition of philosophy which

[1] Address before the Philosophical Union, University of California at Los Angeles, February 17, 1932.

[2] See Pliny, "Hist. Nat.," VIII, 16.

reads: "Philosophie ist der systematische Misbrauch einer eigens zu diesem Zwecke erfundenen Terminologie."[3] However this may be, it is abundantly evident that scientists and philosophers now have almost insurmountable difficulties in talking with each other, and indeed among themselves, because of a new Babel of tongues.

This afternoon I am particularly impressed by this latter difficulty, since I wish to describe to you, in ordinary English, results which can only be obtained by using the language of a special and somewhat complicated branch of mathematics. For this reason I shall confine my mathematics to a few equations which will be projected on the screen, and shall be forced, I am afraid, to say some things which are not very detailed and precise but which will I hope convey a moderately correct impression.

The Problem of Cosmology

For the scientist the problem of cosmology lies in an attempt to describe and understand the structure and behavior of the physical universe as a whole, looked at from a large-scale point of view which considers the average distribution and properties of the matter and radiation of which the universe is constructed, but neglects local details such as the structure of our own earth and solar system, or even the particular arrangement of stars in our own galaxy. Indeed, the scale of view is so large that the contents of the universe are in some ways treated like a fluid with the stars taking the place of atoms and the galaxies or nebulae playing the rôle of molecules.

The method of attacking this problem of cosmology is twofold, observational and theoretical.

For the observational material we must depend on the astronomer, in particular on the remarkable work of Hubble at the Mount Wilson Observatory. With the 100-inch telescope it has been possible to penetrate to a depth of about 10^8 (one hundred million) light-years, way beyond the limits of our own galaxy of stars, whose diameter is only of the order of 10^5 (one hundred thousand) light-years. Scattered throughout all this region at great distances from one another we find numerous nebulae, some millions in all, which themselves appear to be great collections of stars similar to our own milky way. These nebulae are grouped to a certain extent in clusters, but from a large-scale point of view they may be regarded as distributed with a reasonable uniformity, and in particular show no tendency to decrease in concentration as we go farther and farther out into space. A specially important characteristic in the light from the nebulae is a shift towards the red in the position of their spectral lines, this red shift increasing proportionally to the distance out to the nebula. As to the contents of extra-galactic space other than the nebulae, for example, dust and radiation, we can say very little. Owing to the great volume of space between the nebulae, Hubble estimates that the amount of matter spread out in the universe in the form of dust could be several thousand times as great as that concentrated in the nebulae themselves, without producing effects which so far would have been detected. And on the other hand, I have calculated that the temperature of intergalactic space would only have to be 12 degrees absolute to give a density of radiation as large as Hubble's averaged out density of matter.

The theoretical method of treating the problem of cosmology is the one which we are to discuss this afternoon. It has three tasks: first, the interpretation of the findings of the astronomer in terms of accepted or acceptable theory; second, the extrapolation of the findings of the astronomer farther out into space and forward and backward in time together with the prediction of additional phenomena; and third, investigations to determine the conceivable properties which the universe could have in accordance with satisfactory theory.

All three of these tasks are attacked by constructing conceptual models of the universe, in accordance with the principles of theoretical physics, and then investigating the properties and behavior of these theoretical models, for purposes of comparison with what we know or might find in the actual universe. These models are highly abstract and idealized, as contrasted with the actual universe; indeed, they have to be in order to make it possible to treat them with the mathematics at our disposal. When our main interest lies in the interpretation or extrapolation of some property of the actual universe, which has already been observed by the astronomer, we construct conceptual models which exhibit this property and of course as far as possible the other known properties of the actual universe. But when we are searching for the conceivable properties which the universe could have and which might sometime become subject to observation, we allow ourselves great latitude in the kind of models that we study. For example, even though the actual universe is known to contain matter, we may find it informing to consider the properties of a cosmological model which is completely empty, as was done by de Sitter, or one which contains nothing but radiation, as has been done by Silberstein and by myself.

The Principles for Constructing the Models

We must now inquire into the principles on which the cosmological models are to be constructed. This is a matter of the greatest importance, since the chief

[3] Told to me by my colleague, Professor Fritz Zwicky. "Philosophy is the systematical misuse of a terminology specifically invented for this purpose."

difference between the work of the theoretical scientist in trying to understand the properties and behavior of the universe and the fantastic speculations of amateur cranks lies in the attempt of the scientist to make his considerations conform to a satisfactory theory.

The first requirement for the construction of acceptable cosmological models is that they shall conform to the principles of mechanics. For this purpose it is not sufficient to use the classical mechanics of Newton, which has been found to give a correct description of mechanical phenomena in a limited region of space and in the absence of strong gravitational fields. It is necessary, instead, to use the relativistic mechanics of Einstein, which contains the Newtonian mechanics as an approximation, and in addition meets the three so-called crucial tests of relativity, by giving correct predictions of the motion of the perihelion of Mercury, of the bending of light in passing the sun and of the shift in the wave-length of light that originates in a strong gravitational field.

It would be too difficult and time-consuming a task to try to give a logical presentation of the axioms of relativistic mechanics and their physical interpretation. I may call your attention, however, to some of the fundamental equations.

The space-time continuum in which physical events take place is regarded as characterized by a line element of the form

$$\begin{aligned} ds^2 &= g_{11}dx_1^2 + 2g_{12}dx_1dx_2 + \cdots + g_{44}dx_4^2 \\ &= g_{\mu\nu}dx_\mu dx_\nu \qquad (g_{\mu\nu} = g_{\nu\mu}) \end{aligned} \tag{1}$$

where x_1, x_2, x_3 and x_4 are the spatial and temporal coordinates and the $g_{\mu\nu}$ are the ten gravitational potentials. The motion of light rays and material particles in this space-time is given by the equations

$$ds = 0 \qquad \text{(For light rays)} \tag{2}$$

$$\delta \int ds = 0 \qquad \text{(For particles)} \tag{3}$$

And the dependence of the gravitational potentials on the distribution of matter and energy is given by the ten equations

$$-8\pi T_{\mu\nu} = G_{\mu\nu} - \tfrac{1}{2} G g_{\mu\nu} + \Lambda g_{\mu\nu} \tag{4}$$

where $T_{\mu\nu}$ is the energy-momentum tensor, $G_{\mu\nu}$ and G are obtained from the Riemann-Christoffel tensor by contraction, and Λ is the so-called cosmological constant. Although the precise value of the quantity Λ is unknown, we do have observational evidence that shows that it is in any case a very small quantity. Hence we should prefer to take it zero if possible.

In addition to applying relativistic mechanics in the construction of cosmological models, I have found that it is also necessary to apply the principles of relativistic thermodynamics. For this purpose an extension of thermodynamics to general relativity was needed. To obtain this[4] I have taken as the analogue of the first law of classical thermodynamics the known relativistic equation

$$\frac{d\mathfrak{T}_\mu^\nu}{dx_\nu} - \tfrac{1}{2}\mathfrak{T}^{\alpha\beta}\frac{dg_{\alpha\beta}}{dx_\mu} = 0 \tag{5}$$

which corresponds in relativistic mechanics to the classical principles of the conservation of energy and momentum. And I have taken as the analogue of the classical second law of thermodynamics an expression

$$\frac{d}{dx_\mu}\left(\varphi_0\sqrt{-g}\,\frac{dx_\mu}{ds}\right)dx_1\,dx_2\,dx_3\,dx_4 \geqq \frac{dQ_0}{T_0} \tag{6}$$

which can be shown to be a covariant generalization of the usual second law. The quantity φ_0 in this expression is the proper entropy density of the thermodynamic fluid as measured by a local observer, the quantities dx_μ/ds the components of the macroscopic "velocity" of the fluid, dQ_0 the heat as measured in proper units flowing into the region $dx_1\,dx_2\,dx_3$ in the time dx_4, and T_0 the proper temperature. The equals sign ($=$) applies to reversible processes and the sign "is greater than" ($>$) to irreversible processes.

Static Cosmological Models

Let us now turn to the actual cosmological models that have been constructed in accordance with these principles.

The first of these was the famous static model of Einstein[5] with the line element

$$ds^2 = -\frac{dr^2}{1 - r^2/R^2} - r^2d\theta^2 - r^2\sin^2\theta d\varphi^2 + dt^2 \tag{7}$$

where R, the so-called "radius" of the model, is a constant. This line element corresponds to a permanent uniform distribution of matter and energy, having from a large-scale point of view the pressure p and density ρ as given by the equations

$$8\pi p = -\frac{1}{R^2} + \Lambda \tag{8}$$

$$8\pi\rho = \frac{3}{R^2} - \Lambda \tag{9}$$

Although the study of this model has been very instructive, two objections to it may be immediately mentioned. In the first place being a static model it prescribes a state of rest for the heavenly bodies and gives no account of the apparent recession of the nebulae as shown by the red-shift in the lines of their spectra. And in the second place it necessitates a positive value of the cosmological constant Λ to prevent the expression for the pressure from becoming

[4] Tolman, *Proc. Nat. Acad.*, 14, 268, 701, 1928; *Phys. Rev.*, 35, 876, 896, 1930.

[5] Einstein, "Berl. Ber.," p. 142, 1917.

negative, and as mentioned before we should be glad to set $\Lambda = 0$ if possible.

The second relativistic cosmological model to be constructed was that of de Sitter[6] with the line element

$$ds^2 = -\frac{dr^2}{1 - r^2/R^2} - r^2 d\theta^2 - r^2 \sin^2\theta d\varphi^2 + (1 - r^2/R^2) dt^2 \quad (10)$$

where the radius R is connected with the cosmological constant by the equation

$$\frac{3}{R^2} = \Lambda \quad (11)$$

and the line element corresponds to a completely empty universe with the pressure and density everywhere both equal to zero

$$p = \rho = 0 \quad (12)$$

The most immediate objection to this model is of course its complete emptiness, which means that the matter in our actual universe would produce some distortion away from the proposed form. Furthermore, although it was found that particles introduced into such a universe would undergo complicated motions, provided Λ was not set equal to zero, a good explanation accounting both for the red-shift and the density of distribution of the nebulae was not obtained with this model.

Non-Static Cosmological Models

The two line elements of Einstein and de Sitter are called static, since the gravitational potentials $g_{\mu\nu}$ do not depend on the time. Since neither of these models is found to agree with observational facts, it is first natural to inquire if perhaps some other static line element would give an explanation of the red-shift. Some years ago, however, I found[7] it possible to prove that the Einstein line element and the de Sitter line element are the only possible *static* ones which would correspond to a universe having homogeneous properties throughout, and suggested that the study of *non-static* line elements would be very interesting, especially since static line elements take no explicit cognizance of any general evolutionary processes that may be occurring in the actual universe.

As a matter of fact, such studies had already been initiated by a gifted Russian, Friedman,[8] who had given in 1922 an expression for the very non-static line element that is now the subject of so much investigation. The derivation which he gave for the line element is not entirely satisfying, and he considered no direct physical application of his results. He had, however, a masterful grasp of the problem and in spite of the lack of attention that has been paid to his article should receive credit as the originator of the new chapter in cosmology.

This non-static line element can be written in the form

$$ds^2 = -e^{g(t)}\left(\frac{dr^2}{1 - r^2/R^2} + r^2 d\theta^2 + r^2 \sin^2\theta d\varphi^2\right) + dt^2 \quad (13)$$

where R is a constant and the dependence of the line element on the time is given by the exponent $g(t)$. This line element corresponds to a homogeneous distribution of matter and energy having the pressure p and density ρ

$$8\pi p = -\frac{1}{R^2} e^{-g} - \frac{d^2g}{dt^2} - \frac{3}{4}\left(\frac{dg}{dt}\right)^2 + \Lambda \quad (14)$$

$$8\pi\rho = \frac{3}{R^2} e^{-g} + \frac{3}{4}\left(\frac{dg}{dt}\right)^2 - \Lambda \quad (15)$$

which will in general be changing with the time owing to their dependence on the quantity g, which is itself a function of the time. As has been specially emphasized by Einstein, this line element would not require a value of Λ differing from zero in order to prevent the pressure from becoming negative provided d^2g/dt^2 is negative.

The first application of this non-static line element to the phenomena of the actual universe was made by Abbé Lemaitre,[9] of the University of Louvain, who noted that the line element would correspond to an expanding model of the universe if g is increasing with the time, and showed that this would permit an immediate explanation of the mysterious red-shift in the light from the nebulae, since in an expanding universe the nebulae would be moving away from us and this would be expected to increase the wavelength of the light that we receive from them by what is known as the Doppler effect. His detailed treatment contained an unnecessary and improbable assumption as to the value of the cosmological constant Λ, and a specialization which would rule out the presence of radiation and the transformation of matter into radiation in the universe; but the important discovery that the red-shift in the light from the nebulae can be interpreted with the help of an expanding model of the universe is due to him.

The work of Lemaitre was followed by a very fundamental article by Professor Robertson,[10] of Princeton, giving a derivation of the non-static line element for the universe based on very general mathematical assumptions, and by a derivation of my own[11] based on the physical assumption that we can regard the material filling the universe, from a large-scale point of view, as having uniform prop-

[6] de Sitter, *Monthly Notices, R.A.S.*, 76, 77, 78, 1916–1917.

[7] Tolman, *Proc. Nat. Acad.*, 15, 297, 1929.

[8] Friedman, *Zeit. Phys.*, 10, 377, 1922.

[9] Lemaitre, *Ann. Soc. Sci. Bruxelles*, 47, Series A, 49, 1927.

[10] Robertson, *Proc. Nat. Acad.*, 15, 822, 1929.

[11] Tolman, *Proc. Nat. Acad.*, 16, 320, 1930.

erties at a given time throughout the whole of space. At the time I did not know of the previous work that had been done in this field and was led to investigate non-static models from the consideration that the transformation of matter into radiation, which appears to be taking place everywhere throughout the universe, would necessarily lead to a non-static line element. The result obtained showed that it was possible to account both for the transformation of matter and the recession of the nebulae with the help of a non-static line element.

A very powerful additional argument in favor of the non-static line element for the universe was then presented by Eddington,[12] who showed that even if we should start with a static Einstein model of the universe, this would be unstable and would change to a non-static model as the result of small disturbances. The non-static line element for the universe was then also considered by de Sitter[13] who calculated the theoretical course of expansion and contraction for a large number of different conceptual models, assuming that the transformation of matter into radiation could be neglected and assuming the general form of the non-static line element, but making different assumptions as to the unknown quantities R and Λ in the equations.

Since then there have been many further articles[14] on the non-static line element, not only because there are many special problems to be considered into which we can not go here, but also because our knowledge of the actual universe is still too limited to allow a decision between different specific possibilities which would be in accord with the general form of the non-static line element. For this latter reason it is profitable for the theoretical physicist to consider many different conceptual possibilities as to the universe, in advance, and perhaps sometimes generations in advance, of the observational possibilities available to the astronomer. As a result of all the work that has been done, nevertheless, there has grown the increasing conviction that it is an entirely sensible procedure to attempt to explain the once mysterious redshift in the light from the extra-galactic nebulae as due to an expansion of the universe, or, at the least, of that part of the universe which we have so far observed.

[12] Eddington, *Monthly Notices, R.A.S.*, 90, 668, 1930.

[13] de Sitter, *Bull. Astron. Inst. Netherlands*, 5, 211, 1930; *ibid.*, 6, 141, 1931.

[14] Tolman, *Proc. Nat. Acad.*, 16, 409, 1930; *ibid.*, 16, 511, 1930; *ibid.*, 16, 582, 1930; McRae and McVittie, *Monthly Notices, R.A.S.*, 91, 128, 1930; McVittie, *Monthly Notices, R.A.S.*, 91, 274, 1930; Laue, *Naturwiss.*, 19, 530, 1931; Einstein, "Berl. Ber.," p. 235, 1931; Takēuchi, Proc. Phys. Math. Soc. Japan 13, 166, 1931; Heckmann, *Nachr. Wiss. Goettingen*, II, p. 126, 1931; McRae and McVittie, *Monthly Notices, R.A.S.*, 92, 7, 1931.

Application of Relativistic Thermodynamics to Cosmological Models

The foregoing studies of cosmological models have all been based on relativistic mechanics. To complete our considerations we must also consider the thermodynamic aspects of their behavior. This has appeared specially important to me and has engaged a good deal of my attention.

In the case of the older static models no thermodynamic studies were necessary, since nothing at all ever happened in these static models. In the case of the newer non-static models, however, we must inquire into the compatibility of their behavior not only with the principles of relativistic mechanics, and hence with the relativistic form of the first law of thermodynamics, but also as to compatibility with the relativistic form of the second law of thermodynamics. By doing so we gain, I think, two important extensions in our ideas as to the kind of process which might take place in the universe, without contradicting the rules enforced by that disintegrating ogre, the second law of thermodynamics.

The first of these extensions has to do with the occurrence of thermodynamically reversible processes, that is, processes which take place without increase in entropy and without dissipation of energy. In the classical thermodynamics, disregarding purely mechanical changes, it was found that no processes could take place both at a finite rate and at the same time reversibly without increase in entropy. To make processes reversible, it was found necessary to carry them out at an infinitesimally slow rate, in order to obtain, so to speak, the perfect efficiency necessary for reversibility. In relativistic thermodynamics, however, we find a possibility for certain reversible processes to take place both at a finite rate and without increase in entropy, owing to the possibility of correlated changes in entropy density and gravitational field which were neglected in the older theory. This is a matter of some importance, since in the past we have felt that we would be obliged to interpret any thermodynamic change taking place in the universe at a finite rate as evidence that the universe was necessarily running down.

I have considered this new possibility in connection with two different conceptual non-static models of the universe,—one containing nothing but radiation,[15] and the other containing an equilibrium mixture of radiation and perfect gas.[16] It was found that both of these models could expand or contract at a finite rate and yet reversibly without increase in entropy —the first necessarily so, and the second under the additional assumption that the rates of transformation

[15] Tolman, *Phys. Rev.*, 37, 1639, 1931.

[16] Tolman, *Phys. Rev.*, 38, 797, 1931.

of matter into radiation and the reverse were fast enough to maintain equilibrium conditions. It was also shown that there would be a number of phenomena in these models, such, for example, as the outward flow of radiation in an expanding model, which would be interpreted by an ordinary observer familiar only with the classical thermodynamics as definite evidence for the irreversible dissipation of energy into the "cold depths" of space, in spite of the fact that from the more legitimate point of view of relativistic thermodynamics everything would really be taking place entirely reversibly.

It is also to be noted that in the case of processes which take place reversibly without increase in entropy there would be no thermodynamic hindrance to a repetition of the same process over and over again. And, indeed, in the case of the two models just mentioned I have been able to show that they could undergo a continued succession of identical expansions and contractions, without ever coming to a state of rest, provided the cosmological constant in Einstein's equations is zero or negative.[17]

The second extension provided by relativistic thermodynamics in our ideas as to the kind of changes that can take place without contradicting the second law of thermodynamics has to do with the results to be expected when irreversible processes take place. The consideration of irreversible processes is very necessary, since, although we can imitate some of the important phenomena in the actual universe with the help of models that change reversibly, it is evident that reversible processes form only a limited class of the totality of conceivable thermodynamic processes. And we can not expect that the phenomena of the actual universe are all of them really reversible.

In accordance with the classical thermodynamics, when irreversible processes take place in an isolated system, the energy of the system has to remain constant on account of its isolation, and the entropy can then only increase to the upper maximum value which is consonant with this energy. This upper limit corresponds to the most probable internal arrangement of the system attainable with the fixed amount of energy available, and when this limit is reached no further changes would be possible. Hence the classical thermodynamics has accustomed us to believe that the entropy increases taking place in the universe are leading towards a final run-down condition of maximum entropy where all change would cease—the sun and stars cold, all of creation dead and lifeless.

[17] Tolman, *Phys. Rev.*, 38, 1758, 1931. Such expansions and contractions also occur in the case of a model previously treated by Einstein (Ref. 14) which was, however, of such a simple mechanical nature as not to suggest the application of thermodynamics.

In relativistic thermodynamics, however, a different condition of affairs arises, owing to the fact that the principles of relativity do not prescribe a constant value for the total integrated proper energy of an isolated system. For this reason when irreversible processes take place in an isolated system the accompanying increase in entropy is not necessarily subject to the limit imposed in the classical mechanics by a fixed value of the energy, and the possibility arises for isolated systems in which the entropy would continue to increase without ever reaching a maximum value where all change would have to cease.

I have examined this possibility in connection with non-static models of the universe,[18] and have found it possible, if the cosmological constant is zero or negative, to construct conceptual models in which irreversible processes, such as the transformation of matter into radiation under non-equilibrium conditions, would take place, and nevertheless which would show a continued succession of expansions and contractions of increasing amplitude without ever coming to that dreadful final state of quiescence predicted by the classical thermodynamics.

Evaluation of the Results

This completes the description of cosmological models which I had in mind, and we may now ask how far has the theoretical physicist been successful in his three tasks of explanation, of extrapolation and prediction, and of investigation into the conceivable properties that the universe might theoretically have.

In his first task I think that the physicist has been reasonably successful, since he has been able to construct models in accordance with the principles of physics which agree with the findings of the astronomer in at least four ways. They contain a finite density of matter; this matter is uniformly distributed; the gradual transformation of matter into radiation is permitted; and the light from distant objects would show a red-shift approximately proportional to the distance.

As to his second task, that of extrapolation and prediction, I do not think that as yet he has been very successful. He has indeed been able to make one prediction as to a relation that should be found between the apparent diameter, luminosity and red-shift of the nebulae,[19] which can be subjected to observational test. As to the extrapolation of present findings to great distances, however, neither the astronomer nor the physicist can now say whether or not the density of matter and rate of expansion

[18] Tolman, *Phys. Rev.*, 39, 320, 1932.
[19] See Tolman, second article, ref. 14.

remain approximately the same as has been observed out to 10^8 light years, and we can not yet even tell whether the universe is finite or hyperbolic.[20] And although we can completely describe the life history of special models, nevertheless, if we desire to extrapolate in time for the actual universe, we can merely say with some confidence that the process of expansion has lasted for an enormous time in the past and will continue for a very long time in the future.

In the third task of investigating the conceivable theoretical properties of the universe, there has perhaps been somewhat more success, since the conceivable is subject to less rigorous constraints than the actual. And I think the new thermodynamic possibilities which I have described to you are of considerable interest.

Possible Philosophical Bearings

In conclusion I should like to make a few remarks which may have a certain philosophical bearing.

First, I wish to call your attention to the consideration that although the principles of the physical theory for treating such problems as the one we have described must of course in any case agree with observational facts, these principles are actually suggested to the theoretical physicist in two ways—not only as immediate generalizations of experimental findings, but also as desiderata for the inner harmony and simplicity of the theoretical structure he is attempting to build. We must admire Galileo for insisting on observational fact as the ultimate arbiter, and thus breaking away not from Aristotle but from a decadent Aristotelian tradition. And we must admire him for his power and skill in obtaining physical principles from the immediate generalization of experimental facts. But we must not let this just admiration blind us to the power and skill of those other theoretical physicists who obtain the suggestion for physical principles from the inner workings of the mind and then present their conclusions to the arbitrament of experimental test.

This method of proceeding finds a supreme illustration in Einstein's discovery of the system of relativistic mechanics which we have used in constructing our cosmological models. Einstein did not and could not have based his theory merely on attempts to generalize from the known fact that the orbit of Mercury showed an extremely slight deviation from that predicted by Newtonian mechanics. He built his theory rather on two fundamental principles, the principle of equivalence and the principle of covariance, which suggest themselves on grounds of simplicity, generality and logicality; and the theory so obtained was then found to contain not only an explanation for the orbit of Mercury but predictions as well of those other phenomena which have since been verified.

The next matter to which I wish to direct your attention once more is the highly abstract, simplified and idealized nature of the cosmological models that we construct, as compared with the actual universe. This is nothing new in physics, but illustrates a procedure always employed to a greater or less degree in theoretical considerations. It is analogous to the rigid weightless levers of simple mechanics, or the spherical, rigid and perfectly elastic molecules of the simple kinetic theory of gases. The reason for this idealization is obvious. Without such simplifications as are provided, for example, by the assumption of a uniform, homogeneous distribution of matter and radiation throughout our model, the already difficult mathematics would become extremely hard to handle. If, however, we find that our simplified models exhibit such properties as a transformation of matter into radiation and a red-shift in the light from distant objects, we can have a feeling of comfort when we discover these phenomena in the actual universe. And if we discover hitherto unsuspected thermodynamic properties in some of our models, we can at least keep our eyes open for such possibilities in the actual universe.

As a final remark that might have some philosophical interest, I should like to emphasize the special danger in the field of cosmology of the evils of autistic or wish-fulfilling thinking. In studying the problem of cosmology we are immediately aware that the future fate of man is involved in the issue, and we must hence be particularly careful to keep our judgments uninfected by the demands of religion, and unswerved by human hopes and fears. Thus, for example, what appears now to be the mathematical possibility for a highly idealized conceptual cosmological model, which would expand and contract without ever coming to a final state of rest, must not be mistaken for an assertion as to the properties of the actual universe, concerning which we still know all too little. To conclude then: Although I believe it is appropriate to approach the problems of cosmology with feelings of awe for their vastness and of exultation for the temerity of the human spirit in attempting their solution, they must also be approached at the same time with the keen, balanced, critical and skeptical objectivity of the scientist.

[20] See Heckmann, ref. 14.

OBITUARY

WILSON ALWYN BENTLEY

WILSON ALWYN BENTLEY, member of the American Association for the Advancement of Science and fellow of the American Meteorological Society, was born at Jericho, Vermont, on February 9, 1865. Here he lived the whole of his quiet life, and here died on December 23, 1931. One of his great-grandfathers, Roger Stevens, on his father's side, was a soldier through the Revolutionary War. A great-aunt, Anna Bentley, married Martin Chittenden, twice governor of Vermont. His father, Thomas Edwin Bentley, was an up-to-date farmer for his time and place. His mother, Fannie Eliza Bentley, was a daughter of Moses Coleton, a lumber dealer of Bolton, Vermont. He is survived by a brother, C. F. Bentley, of Andover, Vermont, and certain nephews and nieces. He was of the third generation of Bentleys to live at, or near, Jericho, his grandfather being one of the first settlers of that place.

His boyhood was like that of most New England lads on a small farm, uneventful but wholesome. He attended the local public schools, but acquired no further formal education. Thus far nothing whatever in his life had singled him apart for special mention. Then came, by way of his mother, as so many good things do come, the vision that to the end of his days more and more absorbed his attention, and increasingly made the world his debtor. This was when she showed him the beauty of the snow crystal as seen through a small microscope. He was fascinated and began at once to search every snow that came for the more perfect of its fleeting gems. At first he copied what he saw as best he could with pen or pencil, but this was unsatisfactory. The minute details were difficult to represent, and often melted away before he had had time properly to study and copy them. He therefore soon fixed up a photomicrographic camera which afforded accurate and quicker results. He developed his own technique and acquired a remarkable skill, necessary, of course, in dealing with so delicate and so transient a thing as the tiny snow crystal. He taught music one year, 1885–86, but with that exception his young manhood was spent mainly in labor on the farm. During the last 20 years of his life, however, he lived practically alone (he never married) and gave all his time and attention to his pictures, of which he had several thousand, and to which he added many more every winter.

His first article appeared in 1898. After this he contributed a number of papers on frost and the snow crystal to various publications, and furnished many pictures to authors for use in books and magazines. He also gave an occasional lecture on his hobby, and furnished slides for others to use.

Naturally he dreamed of a great book that should contain many hundreds of his pictures of snow and frost. Artists and others also hoped that some suitable publication might be made of this remarkable collection of pictures which it had taken a devoted lifetime to obtain. The realization of his dream was difficult to effect, but at last it was accomplished. Then, after about three weeks of real happiness, he was joined by the "old man's friend," pneumonia.

Thus the drama ends of the kindly "Snowflake Man" of Jericho, whose thousands of pictures long had been classic, and to whose honored doorstep, however secluded and humble, all the world had worn a path in recognition of true worth.

W. J. HUMPHREYS

MEMORIALS

DR. DENMAN W. ROSS has presented to Harvard University a portrait of the late Theodore W. Richards by Kanji Nakamura, to be placed in the Chemical Laboratory.

THE President's Medal of the National Academy of Design was awarded posthumously to Samuel F. B. Morse, artist and inventor of the telegraph. It was presented on March 28 to his son, William Goodrich Morse, at the Metropolitan Museum of Art, where a special loan exhibition of Morse's paintings was held. The President's Medal has been awarded only once before, Mr. Elihu Root being the recipient.

IN connection with the celebration of the hundredth anniversary of the death of Goethe, *Forschungen und Fortschritte,* Berlin, has published a special number reviewing Goethe's contributions to science, including mathematics, vision, optics, chemistry, geology, meteorology, botany, zoology and anatomy.

A DARWIN exhibition is to be opened at the Communist Academy in Leningrad on April 19, on the fiftieth anniversary of Darwin's death, and a joint meeting of the Communist Academy and the Academy of Sciences is to be held in his honor.

DR. G. CLARIDGE DRUCE, pharmacist and curator of the Fielding Herbarium, Oxford, whose death was reported in SCIENCE last week, has bequeathed his herbarium and library with his house and an endowment for a Botanical Institute at Oxford.

SIR RICHARD WILLIAMS has been appointed president and Professor Gibson treasurer of a fund to purchase for a museum the cottage at Llangerniew, Den-

bighshire, Wales, where Sir Henry Jones, the philosopher, was born.

RECENT DEATHS

Dr. Albert Perry Brigham, professor emeritus of geology at Colgate University, died on April 1, in his seventy-seventh year.

Dean Francis M. Hartmann, professor of electrical engineering and dean of the school of engineering of Cooper Union, died on March 28, at the age of sixty-one years.

Mr. W. W. Ashe, senior inspector in the Forest Service, died on March 18, as the result of an operation. Mr. Ashe is known for contributions in the field of dendrology, his specialty being the hardwoods of the Southeastern United States. He was the author of numerous publications on forestry and had for many years been active in the development of the acquisition of forest lands by the Federal Government.

Professor Henry James Priestley, professor of mathematics and physics in the University of Queensland, died at Brisbane on February 26, at the age of forty-eight years.

The death is announced at the age of fifty-four years of Professor Giuseppe Martinelli, assistant secretary of the Pontifical Academy of Science, Vatican City, and assistant in the Bureau of Meteorology and Geophysics, Rome.

SCIENTIFIC EVENTS

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

According to a statement in the *Experiment Station Record,* this institute was established in Scotland in 1930 through the initiative of Mr. T. B. Macaulay, of Montreal, Canada. Following the purchase and endowment by Mr. Macaulay in 1929 of land for a peat-land demonstration farm on the Island of Lewis in the western Hebrides group, provision was made for the opening of laboratories on the mainland where research connected with Scottish soils in general could be conducted. The institute was accordingly incorporated under a committee of management of eleven members selected by the Department of Agriculture for Scotland and the Scottish agricultural colleges.

A tract of about 50 acres situated at Craigiebuckler on the outskirts of Aberdeen was acquired and equipped with funds contributed by Mr. Macaulay. A large mansion house on the property was fitted up into offices, a library, laboratories and similar purposes. A range of greenhouses was already available, and a cage for pot experiments was constructed in the two-acre walled-in garden. The fields are being laid out into plats to study the effects of lime and different systems of cultivation and manuring, but it is expected that much of the field work of the institute will be carried on in other parts of the country representative of the various soil types.

Funds for the maintenance of the work are at present being provided by the British Development Commission. Close cooperation is being maintained with other institutions in both research and advisory work. The institute has taken over the lysimeter studies of the North of Scotland College of Agriculture at Graibstone, and there have been some curtailments and readjustments at other institutions with a view to the concentration of soil investigations to a large extent at the institute. It is thought that a well-equipped soil institute with an adequate staff will be in a much better position than isolated workers in several different centers to deal with the intricate problems of the very variable soils of Scotland.

In addition to the joint work with the colleges, there will be an increasing amount of collaboration with other research institutions, as in nutrition problems connected with deficiencies in certain soils. The institute is already cooperating with the Scottish Animal Diseases Research Association in questions of malnutrition of mountain sheep and with the Scottish Plant Breeding Station regarding grasses suitable for peat land.

The present staff of the institute consists of a director, Dr. W. G. Ogg; a secretary; a soil geologist; specialists for moorland work, soil surveys and drainage analysis; a technical assistant, and a part-time surveyor and advisory officer who lectures at the West of Scotland College during the winter months. Later it is hoped to add a bacteriologist, an ecologist and an engineer.

THE EDWARD ORTON, JR., CERAMIC FOUNDATION

The Ohio State University Monthly reports that to preserve the enterprise he founded in the interests of the industry to which he gave the best years of his life as a man of science, engineer, teacher and manufacturer, the Edward Orton, Jr., Ceramic Foundation is created by the will of General Edward Orton, Jr., who died on February 10. The will was probated on February 24.

The foundation is established for two purposes: to continue the manufacture and sale of the highest grade pyrometric cones, used in industry, and to use the profits therefrom to advance "the ceramic arts and industries in the United States." Under the will, the

estate is divided into two parcels. The first, comprising General Orton's cone manufacturing business, known as the Standard Pyrometric Cone Co., will be used to establish the foundation. The second will consist of the residue of the estate and is left to Mrs. Orton.

The proceeds of a life insurance policy for $10,000 are left to the Ohio State University for the maintenance there of the Edward Orton Memorial Library of Geology, which General Orton had established in memory of his father, the first president of the university, and to which he had annually given $500 for books.

The will sets up a self-perpetuating board of trustees to administer the foundation. It will consist of the following: The president of the Ohio State University, a representative of the U. S. Bureau of Standards, the head of the engineering experiment station of the Ohio State University, the head of the department of Ceramic Engineering of the Ohio State University, the secretary of the American Ceramic Society and one other representative of the society chosen for a three-year term, and an attorney. The trustees will receive $1 a year and expenses. The trustees are to organize within 90 days and take over the cone business and provide for its operation. The will designates Colonel Simeon Nash, General Orton's attorney, as the attorney member of the board.

If for any reason it becomes impossible to continue to operate the business successfully, the trustees are authorized, with approval of the probate court, to close the business and to turn the assets over to the Ohio State University as part of the irreducible debt of the state of Ohio, the income therefrom to be used for ceramic research either through the university's department of ceramic engineering or its experiment station.

The research division of the foundation may be set up as a part of the cone manufacturing establishment or separately, at the discretion of the trustees. In the latter case, the will suggests, it "would be used principally to stimulate and assist research, and to coordinate, supervise and supplement researches undertaken in the ceramic department and engineering experiment station of the Ohio State University, or by other laboratories or groups of laboratories. . . ." In such case also the research director would be authorized to "furnish personnel or loan equipment to laboratories cooperating with him." The will further provides that results of research promoted by the foundation shall be published "to the end that said results shall be given freely to the public and made available for ceramic engineering use."

The board of trustees is directed not to "sell or permit its agents and employees to sell, or to make any charge, direct or indirect, for any information furnished through or by said research department, to the end that all surplus over and above the cost of production made upon the sale of Standard Pyrometric Cones shall be returned to the ceramic industries in the form of technical knowledge."

The will further provides that, since the estate is "severely depleted" because of the creation of the trust and there has thus been taken from it "its chief income producing element," for five years there shall be paid to Mrs. Orton specified sums from current earnings of the cone business. Mrs. Orton and Colonel Nash were named coexecutors of the will, which requested that they be not required to furnish bond.

MARINE EXPEDITION TO THE WEST INDIES

THE International Expedition to the West Indies completed its work at Miami on March 19. The major results of the expedition include 4,000 miles of sonic sounding and 64 gravity stations at sea and on the island. The maximum depth registered in the Bartlett Trough was 4,000 fathoms, which is supposed to be 400 fathoms deeper than shown on any previous soundings. Twenty-nine of the gravity stations at sea have already been computed and, while it is perhaps too early to make a definite statement as to the major structural characteristies of the West Indian region and especially of the Bahamas, it would appear as if the Bahama region as a whole was acting as a single block of the earth's crust and that this block has undergone vertical movements of the first order.

The determination of gravity on the islands has been under the direction of Lieutenant Joseph P. Lushene, who operated from the yacht *Marmion*, loaned and navigated by Mr. Hugh Matheson, of Miami. Owing to the skill of Mr. Matheson and Lieutenant Lushene, this unit of the expedition succeeded in making 12 gravity stations in approximately 30 days.

The council and personnel of the expedition are deeply indebted to the U. S. Navy, and especially to the personnel of the submarine S-48 and the rescue vessel *Chewink* for their interest and extreme helpfulness in carrying out the program of sonic sounding and determination of gravity at sea. Dr. F. A. Vening Meinesz, who was in charge of the most important part of the program, was assisted by a representative of the Naval Laboratories and Mr. Harry Hess, Procter fellow of geology at Princeton University. Dr. Meinesz and Mr. Hess are at present of the opinion that, while the Bartlett Trough is, as has already been supposed, largely a structural feature and at present probably the main zone of weakness

the region, the relatively deep areas of the sea, such as Exuma Sound, the Tongue of the Ocean and Providence Channel, suggest the possibility of being drowned river valleys. It will probably be two or three months before the gravity stations and isostatic reductions have all been computed, and it is hoped that the geological significance of the expedition can be reported at that time.

RICHARD M. FIELD

PRINCETON UNIVERSITY

THE PULLMAN MEETING OF THE PACIFIC DIVISION OF THE AMERICAN ASSOCIATION

A PRELIMINARY announcement of the Pullman meeting has just been distributed to members of the American Association for the Advancement of Science resident in British Columbia, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah and Washington.

Two of the principal addresses to be presented during the meeting will be given by Professor A. O. Leuschner, president of the Pacific Division, and Professor J Harlen Bretz, of the University of Chicago. The subject of Professor Leuschner's address will be "The Astronomical Romance of Pluto." The events that led to the discovery of Pluto, the investigations on its orbit and mass and the question of its nature as a celestial object will be discussed. Professor Bretz's address, which will be on "The Scablands of the Columbia Plateau in Washington," is of special interest in view of a general symposium to be held on "Scientific Problems of the Columbia Plateau."

Under this heading, four topics will be introduced for discussion in the session of Thursday morning, June 16:

Interesting Botanical Areas, Dr. F. L. Pickett, professor of botany, the State College of Washington.

Geological Problems, Mr. M. G. Hoffman, assistant professor of petrology, the State College of Washington.

Economic and Agricultural Problems of the Wheat and Apple Industries, Dr. E. F. Dummeier, professor of economics, the State College of Washington.

Engineering Problems, Dean Ivan C. Crawford, dean of the College of Engineering, the University of Idaho.

In accordance with the custom of recent years, the opening session on Wednesday, June 15, will be devoted to research reviews. The purpose of these is to survey the progress of scientific research on the Pacific Coast and in the Far West, the subjects under investigation being reviewed in the light of their relation to problems of major interest in the sciences at large. Attention will be centered upon a few of the most noteworthy accomplishments in each field. The reviews will be presented as follows:

Astronomy and Astrophysics: Dr. J. S. Plaskett, Dominion Observatory, Victoria, B. C.

Chemistry: Dr. J. B. Ramsey, University of California at Los Angeles.

Physics: Dr. W. V. Houston, California Institute of Technology.

Animal Sciences: Dr. J. E. Guberlet, University of Washington.

Plant Sciences: Professor G. J. Peirce, Stanford University.

The greater part of Thursday and Friday will be given over to the programs of the participating societies. Members proposing to present papers are reminded that titles received later than May 2 can not be published in the association program.

A visit to the University of Idaho, and excursions to Kamiak Butte, Almota Canyon, Moscow Mountain, Bald Butte, Snake River Canyon, Wallowa Mountains and the Scablands are under arrangement. Areas of considerable interest to the biologist and geologist will be visited.

SCIENTIFIC NOTES AND NEWS

THE honorary doctorate of laws was conferred on March 23 by the University of California on Dr. William Wallace Campbell, formerly director of Lick Observatory and from 1923 to 1930 president of the university.

DR. GRAHAM LUSK, professor of physiology in the Cornell Medical College, was recently elected a corresponding member of the Prussian Academy of Sciences.

DR. CHARLES B. DAVENPORT, director of the Station for Experimental Evolution of the Carnegie Institution of Washington, has been elected a member of the German Academy of Sciences at Halle.

THE Priestley Medal of the American Chemical Society has been awarded to Dr. Charles L. Parsons, since 1907 secretary of the society.

THE prize of $1,000 of the American Chemical Society, founded in 1931 by Dr. A. C. Langmuir, has been awarded to Dr. Oscar K. Rice, instructor in chemistry at Harvard University. The prize is awarded to the most promising chemist in North America, less than thirty years old, in recognition of outstanding research in pure chemistry. Dr. Linus Pauling, of the California Institute of Technology, received the award last year.

AT the annual meeting of the Physical Society,

London, on March 18, the Duddell Medal was presented to Professor C. T. R. Wilson, F.R.S.

DR. EDWIN STEPHEN GOODRICH, Linacre professor of zoology and comparative anatomy, University of Oxford, has been selected by the council of the Linnean Society of London as the recipient of the Linnean Medal, which will be presented to him at the anniversary meeting on May 24.

THE Meldola Medal, the gift of the Society of Maccabaeans, was presented on March 1 to Dr. G. F. Marrian, of University College, London, in recognition of his researches on vitamins and hormones, at the fifty-fourth annual general meeting of the British Institute of Chemistry.

IN recognition of his services to Queen's University, Belfast, where he had been professor of surgery for thirty-seven years, Dr. Thomas Sinclair was recently presented with a portrait of himself by Mr. George Harcourt. Viscount Bangor, who presided, referred to Professor Sinclair's career in the army, the Imperial Parliament and the Senate of Northern Ireland. Sir Thomas Houston spoke particularly of the debt that the Belfast school and his former pupils owed to Dr. Sinclair.

A PORTRAIT of Dr. J. Parsons Schaeffer, professor of anatomy at the Jefferson Medical College and director of the Daniel Baugh Institute of Anatomy, was presented to the college on March 15 by the graduating class. The portrait was painted by Lazar Raditz, of Philadelphia.

FOR outstanding contributions to progress in the medical science, Dr. Elliott Proctor Joslin, of the Harvard Medical School, and Dr. Aleš Hrdlička, of the Smithsonian Institution, have been awarded the 1932 honors of the Kober Foundation, Georgetown University. Dr. Joslin, authority on diabetes mellitus, will receive the foundation's medal at the meeting in Atlantic City of the Association of American Physicians on May 3. Dr. Hrdlička, curator of physical anthropology at the Smithsonian Institution, has been designated foundation lecturer for this year.

DR. GEORGE R. LA RUE, professor of zoology at the University of Michigan and director of the Biological Camp at Douglas Lake, was elected president of the Michigan Academy of Science, Arts and Letters at the conclusion of the annual meeting at Ann Arbor. Mr. Robert B. Newcomb, of the State Department of Conservation, was elected vice-president.

SIR WILLIAM J. POPE, professor of chemistry in the University of Cambridge, has been elected chairman of the Council of the City and Guilds of London Institute in succession to the late Dr. Morton Latham.

LORD MOYNIHAN of Leeds has been elected a member of the committee of the Radium Institute, London, in the place of Sir Hugh M. Rigby, who has resigned on his retirement from practice and removal from London.

THE committee on scientific research of the American Medical Association has made a grant to Professor Arthur H. Smith, of the laboratory of physiological chemistry, Yale University, for the continuation of his studies on the blood of animals subjected to restriction of inorganic salts in the diet.

DR. MAX W. GARDNER, chief in botany in the Indiana Experiment Station, has been appointed professor of plant pathology and plant pathologist at the University of California and the California Experiment Station.

DR. HERBERT E. ROAF, professor of physiology in the London Hospital Medical College, has accepted an offer of appointment to the George Holt chair of physiology at the University of Liverpool, in place of Professor J. S. Macdonald, who will retire at the end of the present session.

AT a general meeting of the governing body of Magdalen College, Oxford, Mr. Eric Balliol Moullin, university reader in engineering science, was elected to a fellowship.

DR. OSKAR SEIFRIED has sailed for Germany, having accepted the professorship of general pathology and pathological anatomy in the veterinary faculty of the University of Munich, succeeding Professor T. Kitt. Dr. Seifried was associate and later associate member in the department of animal and plant pathology of the Rockefeller Institute for Medical Research at Princeton, N. J.

THE REVEREND EMMANUEL M. SANCHEZ-NAVARRO NEUMANN, S.J., who has been in charge of the observatory at Cartuja, near Granada, Spain, and who is known for his researches in the field of seismology, was expelled from his observatory by the new Spanish government on February 2. He is now an exile in Naples, Italy. He was obliged to leave behind the accumulation of twenty-five years of labor with his instruments and books.

DR. W. A. SHEWHART, of the Bell Telephone Laboratories, will sail on April 9 for a two months' trip to Europe. His first engagement will be the delivery of three lectures at the University of London on the rôle of statistical method in industrial standardization. A number of conferences in theoretical and applied statistics with Dr. Shewhart have been arranged both in Great Britain and on the continent.

PROFESSOR HERBERT OSBORN, of the Ohio State Uni-

versity, has returned to Columbus from a winter vacation in Florida and will resume his work for the spring quarter. At the scientific meetings at New Orleans he was the guest of honor at the annual Entomologists dinner. Dr. Osborn addressed the Southern Beekeepers Conference at St. Petersburg, Florida, on February 3 and the zoology students at Rollins College on March 11.

Dr. Arthur J. Tieje, chairman of the department of geology at the University of Southern California, will again give the courses in geology at the summer session of Columbia University. He will drive to New York, with the aim of adding to his collection of rock suites representing the historical geology of the states. Later he will spend a month abroad, collecting European rocks.

Mr. Gerrit S. Miller, Jr., curator of the division of mammals of the U. S. National Museum, is spending two months in Porto Rico, exploring caves for remains of extinct animal bones.

A seven-weeks course of daily lectures and discussions on the principles and methods of hydrology as pertaining to the ground waters was given at the U. S. Geological Survey from February 1 to March 19. The discussions were led by Dr. O. E. Meinzer, Mr. W. D. Collins, Mr. D. G. Thompson, Mr. W. N. White, Mr. A. G. Fiedler and other members of the staff.

Dr. Arthur H. Compton, of the University of Chicago, gave four addresses at the University of Oklahoma, on March 19 and 20. He spoke before the department of physics on "Cosmic Rays and Atomic Nuclei" and "New Experiments on the Structure of the Atom," and before a general university convocation on "Are Man's Actions Determined by Physical Laws?" He was also the principal speaker at the annual banquet of the college of engineering, and was the guest of honor at a department of physics luncheon.

Lectures will be given in the Mallinckrodt Laboratory, Harvard University, as follows: April 11, at 8 p. m., Dr. N. V. Sidgwick, fellow of Lincoln College, Oxford, on "The Structure of Simple Molecules"; April 14, at 4:30 p. m., Professor Peter Debye, of the University of Leipzig, on "The Interionic Attraction Theory of Electrolytes."

Dr. B. A. Keen, assistant director of the Rothamsted Experimental Station, delivered the G. J. Symons memorial lecture before the Royal Meteorological Society, on March 16. The subject of Dr. Keen's lecture was "Soil Physics in Relation to Meteorology."

A lecture under the auspices of the Smithsonian Institution was given at the U. S. National Museum on March 30 on "Plant Records of the Rocks" by Dr. Albert Charles Seward, master of Downing College and professor of botany at the University of Cambridge. During his stay in the United States Professor Seward expects to lecture in Boston, Washington, Chicago, San Francisco and Seattle.

Sir Frank Dyson, Astronomer Royal of Great Britain, will be a member of an expedition that will visit the United States and Canada to observe the total solar eclipse on August 31. Sir Frank will preside at the meeting of the International Astronomical Union which meets at the Harvard College Observatory. Other members of the party will be Dr. Harold Knox-Shaw, president of the Royal Astronomical Society; Sir A. S. Eddington, Plumian professor of astronomy at the University of Cambridge, Lord Raleigh, and Dr. L. J. Comrie, of the Royal Naval College, Greenwich, superintendent of the British Nautical Almanac office.

The fourteenth annual meeting of the American Society of Mammalogists will be held in Washington from May 3 to 7, the sessions for the presentation of papers, discussion and business to convene at the National Museum. The local committee on arrangements consists of Dr. W. M. Mann, director of the National Zoological Park; Dr. Remington Kellogg, assistant curator of the division of mammals; Ernest P. Walker, assistant director of the National Zoological Park, and Mr. Walter C. Henderson and Dr. H. H. T. Jackson, of the Bureau of Biological Survey. According to the plans of this committee, a combined reception, smoker and movies will be held on Wednesday evening, May 4, and the annual dinner on Thursday evening, May 5. On Saturday there will be a luncheon at the National Zoological Park, with a tour of the park in the afternoon.

The Association of American Medical Colleges announces the completion of the third annual study of the accomplishment of students during their first year in medical school. This study includes the class of 1930, numbering 6,315 students, who came from 584 colleges of liberal arts. The record shows how many students made a clear record, how many had an encumbered record and how many failed completely. The name of the student and the medical college attended completes the record. The subjects in which conditions or failures, or both, were made are also carded. Colleges of liberal arts who sent students into medicine in the fall of 1930 may obtain a complete record of the accomplishment of these students by writing to the secretary of the association, Dr. Fred C. Zapffe, 25 East Washington Street, Chicago.

Museum News reports that McGill University, Montreal, will give its summer course in medical museum technique this year from June 13 to 25.

Only eight students will be admitted, and registration for the course will close on April 30. Lectures and demonstrations will be held in the recently built Pathological Institute of the university and students will have an opportunity to examine an extensive and representative collection of museum specimens, including pathological, osteological, anatomical and zoological material. The two weeks course will be devoted to laboratory layout, equipment, lighting, etc., glass frame technique, color preservation, museum jars, mounting of specimens, corrosion and injection, cleaning of bones, osteological preparation, cross sections, clock glass and petri dish mounting, dry mounting, gelatine, cement, records, storage and case exhibits. Students will be given an opportunity of spending an extra week in the laboratory. Inquiries should be addressed to Mr. E. L. Judah, curator of Museums, McGill University, 3755 University Street, Montreal.

AMONG the exhibits displayed on March 9 at a scientific reunion held in the board room of the British Museum of Natural History at South Kensington were, according to the London *Times*, a number of fossil fauna recovered from the site at Oldoway in Tanganyika by Mr. A. T. Hopwood, of the museum staff. The significance of the Oldoway discoveries was discussed by Mr. L. S. B. Leakey, in an article in the issue of the *Times* for March 9, and the exhibits shown at South Kensington included remains of a number of Pleistocene mammals, among them several teeth of the Dinotherium, an aberrant sideline from the family of the elephant. Hitherto this animal has been associated with the Miocene period, but it was found in the Oldoway beds with remains of the elephant itself. A fossilized elephant tooth from this deposit was exhibited yesterday for comparison, together with the mandible and palate of the *Elephas antiquus recki* found in the lowest bed, and associated by European analogies with the Middle Pleistocene period. From this lowest bed and that immediately above it there were exhibited two antelope skulls of a new type and a kudu skull complete with horns. The zoological exhibits included species of the Siphonophora, a very primitive type of animal in which evolution has not yet reached the stage of producing a body cavity; the specimens displayed included tropical, Arctic and Antarctic variations of its sac-like constitution. A new genus of scorpion collected by Mr. Bertram Thomas in Arabia attracted much attention, not merely by its unprecedentedly flattened tail, but through the occasional existence of a tibial spine such as was found in its relatives of the Silurian period and the oldest surviving genus of scorpions to-day, but not in the more recent genera. The department of botany showed specimens of the "Fungus Stone" or "Rock Mushroom," a hard mass of fungal mycelium and earth which, when watered, produces an edible fungus, causing much astonishment to naturalists from the time of Strabo to that of Pepys.

DISCUSSION

BIOLOGICAL ABSTRACTS AND THE COLLEGE

THE question of the advisability of continuing and improving *Biological Abstracts* again arises, now that we have five years' actual experience with the usefulness of the journal. To be sure it is regrettable that the *Abstracts* are not as up to date as might be wished, nor as yet completely indexed, but the undertaking is well launched, and we have the word of the editor, who said at the New Orleans meetings that it needs only a somewhat greater support to improve in those ways where they are now found wanting. In a recent issue of SCIENCE, Dr. Lillie pointed out the unique character of the publication, the fact that in its comprehensiveness (and withal, compactness) there is an immense saving in dollars to biologists, who, to get a similar service otherwise, would have to subscribe to many abstract journals, each only partially covering the field. There seems to be no question of the value of the *Abstracts* to biological research, nor of the value to society, in turn, of that research.

It must be remembered that the *Abstracts* play a part of varying significance in the work of biologists in different types of institutions, and it is the use made of the publication by those of us connected with small colleges which I wish to emphasize. The library appropriations in the colleges are uniformly smaller than those of the universities; any large number of the important journals in the field of biology is therefore quite out of the question for college budgets. Thus every aid in giving to the colleges as wide a survey as possible of what is being done in research is to be commended. *Biological Abstracts* gives such a survey in brief and gives likewise access to the material that can then be temporarily borrowed from the larger loan libraries which so generously provide service of this type. Students in my own college, for example, use *Biological Abstracts* extensively in the preparation of seminar reports and in small research problems. Further, all teachers in small institutions will agree that the *Abstracts* are invaluable aids to teaching, in keeping abreast of the times in fields in

which they do not regularly receive reprints from their colleagues.

Is the situation in the colleges to be considered significant or critical, when admittedly the greatest volume of published research in the biological sciences comes out of the universities? It can be shown, I think, that it is of vital importance. A glance at the "American Men of Science" will show that the American scientists have begun their education in two sorts of institutions, roughly classifiable into small colleges and large universities. A count shows the proportion starting in the smaller schools to be about two for every three starting in the larger ones. But a survey of the total enrolment of students found in those of the two types of schools listed in the above publication shows about four times as many for the larger institutions as for the smaller. (In the *New York Times* of November 16, last year, a list shows approximately as many students in some 600 small colleges as in the larger universities. One can conclude that not all the small colleges have contributed to the "American Men of Science.") Thus, upon consideration of the institutions which any contribution at all to make to productivity as noted in the "American Men of Science," it appears that any given college undergraduate has two and two thirds greater chance of ultimate productivity than any given university undergraduate. Furthermore, the readers of SCIENCE can think of their own early training, and that of their colleagues, to see where a large proportion of them got their first start. An analysis, too, of the present graduate students of promise in any of the universities would indicate a large number coming previously from small colleges. Obviously, if they started in a small college, it must have been there that their interest was stimulated along their chosen line before they sought advanced study in the larger university. Unless we would kill the goose that laid the golden egg, we must not overlook the small schools, even though they be relatively unproductive of important finished research. Let our colleagues in the universities with access to the complete files of the chief journals remember the close relation existing between the colleges and the graduate schools, and help us in feeding to them the student with the inquiring mind.

To take the place of the commercial and industrial concerns standing back of the *Abstracts* of our colleagues, the chemists, we shall probably have to depend always on some sort of philanthropic support outside our circle of scientific investigators and teachers. This is the more true since the number of articles to be abstracted greatly exceeds that in the field of chemistry, and this is a correspondingly greater undertaking. But a united front on the part of the biologists of the country in fully approving the continuance and the continued improvement of *Biological Abstracts*, and their tangible support of the undertaking by subscriptions, will do much. In that direction an unmistakable evidence of support has already been indicated in the well-known fact that the publication in question has more subscribers than any other technical biological journal.

HOPE HIBBARD

OBERLIN COLLEGE

THALLIUM POISONING

DR. BROOKS' recent note in SCIENCE for January 22, 1932, page 105, is unusually interesting. Until about a year ago, I was scarcely aware that such a toxic element as thallium existed. In the *Journal of the American Medical Association*, May 30, 1931, pages 1866–1868, appeared three different articles on the toxic effects of thallium, as used in a cosmetic preparation for removing hair. In the same journal for September 19, 1931, page 851, appeared an account of two fatal cases of thallium poisoning, due to the administration of the acetate as a depilatory in scalp ringworm. The same journal contains various other notes on the toxicity of the element. On January 30, of this year, page 406, is an editorial comment on fatal human cases due to eating poisoned grain. In the issue of February 20, 1932, pages 618–620, is a very complete note on thallium poisoning from a depilatory cream. A discussion of the element, from its discovery to its dangerous therapeutic use and toxic properties, is given. Its toxicity and pathologic effects on higher animals appear to be well known.

It is quite a surprise to learn that it seems to be equally toxic for vegetation. The amount of thallium distributed in poisoned grain for destroying rodents and other forms of life is quite appalling. In its use in destroying ground squirrels, it would be interesting to know if there is any likelihood of the thallium treated grain being placed in the same situation year after year. That is, are the old burrows occupied by incoming ground squirrels? If such is the case, there would seem to be danger of causing patches of soil sterility. All in all, thallium apparently is a dangerous poison, and it would be well to restrict its use in human medicine and wholesale poisoning activities for lower forms of life, until more is known about its action and the habits of the animals against which it is used.

It is interesting to note that the *Journal of the American Medical Association* for February 27, 1932, page 741, contains a news item that the poisonous depilatory cream has been prohibited for sale in San

Francisco. However, the State Department of Agriculture of California (Serial Publication No. 109) uses thousands of pounds of thallium coated grain in rodent control work. In spite of careful supervision, several fatal cases[1] of thallium poisoning in man have already occurred, as well as some losses to domestic animals, according to press dispatches.

MARCUS WARD LYON, JR.

SOUTH BEND, INDIANA

THE EXISTENCE OF AN EXTRA-PANCREATIC (OR CELLULAR) INSULIN IN THE DOG AFTER PANCREATECTOMY?

A RECENT article by Tuttle[1] offers a reinterpretation of some results published by the present writer in the paper entitled "The Utilization of Carbohydrate by Totally Depancreatized Dogs Receiving no Insulin."[2] While granting that the results in question undoubtedly show the utilization of large amounts of carbohydrate by such animals, Tuttle interprets this as being evidence for "the existence of an extra-pancreatic (or cellular) insulin in the dog after pancreatectomy."

I should like to point out that this hypothesis was considered in my paper, but rejected in favor of the "Overproduction Theory of Diabetes," for the following reasons:

(1) The animals did not survive indefinitely, as they do with insulin injections. Nor can the death of these animals be ascribed to the withdrawal of raw pancreas from their diet, as Tuttle suggests. Reference to a later paper by Hershey and the writer[3] will readily show the difference in the time periods involved and the entirely different pictures presented by these two syndromes.

(2) Dogs 1 and 14 (Tables I and IX), which according to the results obtained should have acquired a fairly adequate extra-pancreatic insulin supply, were as "diabetic" as ever when insulin injections were resumed and then discontinued for the second time.

But perhaps a greater objection to Tuttle's contentions is based upon what the writer believes to be a fundamental error in the logic employed. Tuttle's major premise is that "insulin is necessary for the oxidation of glucose." It must be pointed out, however, that this belief is largely based upon the supposedly fixed and peculiar nature of the D:N ratio and the respiratory quotient in the diabetic organism. Since the validity of these phenomena is the very thing which my results have disproven, Tuttle has, in effect, assumed as true the very thing he set out to prove.

SAMUEL SOSKIN

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CHICAGO, ILLINOIS

[1] A preliminary report of these cases appears in the *Journal of the American Medical Association* for March 26, 1932, page 1076.

[1] *New Eng. Jour. Med.*, 206: 8, Jan. 7, 1932.

[2] *Jour. of Nutrition*, iii: 99, Sept., 1930.

[3] *Am. Jour. of Physiol.*, 98: 74, Aug., 1931.

THE MUSKRAT, A NEW HOST FOR PARAGONIMUS

DR. E. W. PRICE[1] has recently described four new species of trematodes from the muskrat, *Ondatra zibethica*, and in the same paper included a key to all the known trematodes of this animal, but the mammalian lung fluke, *Paragonimus*, was not listed. I pointed out in a recent paper[2] that I had been able to infect muskrats with *Paragonimus* in the laboratory, but that I had not found this parasite in a collection of 249 wild muskrats from Michigan, chiefly from the southeastern part of the state. Since that paper appeared, this parasite has been found in wild muskrats from two localities in western Michigan. During November, 1931, four out of 34 muskrat carcasses secured near Manistee for the use of the class in parasitology were found to be infected with *Paragonimus*. Later, two out of 19 carcasses from the same source and four out of 26 from Muskegon examined by me were infected. Three of them bore unusually heavy infections. Thus, during the fall of 1931, 79 muskrats were examined, of which 10 (12 per cent.) were infected.

In the same paper indicated above, I expressed an opinion that the mink is the normal definitive host of *Paragonimus* since a 17 per cent. infection was found in a collection of 563 carcasses of minks from Michigan and northern Ohio. *Paragonimus* was not found in 308 raccoons, 109 opossums, 22 weasels and one badger from the same region examined during the same period. Wallace[3] reported a 7 per cent. infection in 234 minks which he examined at fur farms in Minnesota.

The discovery of *Paragonimus* in such a high percentage of wild muskrats from a limited locality warrants the assumption that, under certain conditions, these animals serve as well as the mink in the capacity of definitive host.

DONALD J. AMEEL

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[1] E. W. Price, "Four New Species of Trematode Worms from the Muskrat, *Ondatra zibethica*, with a Key to the Trematode Parasites of the Muskrat," Proc. U. S. Nat. Mus., 79: art. 4, 1–13, 1931.

[2] D. J. Ameel, "More Data on the Lung Fluke, Paragonimus, in North America," SCIENCE, n. s., 74: 493–494, 1931.

[3] F. G. Wallace, "Lung Flukes of the Genus Paragonimus in American Mink," *Jour. Am. Vet. Med. Asso.*, 31: 225–234, 1931.

CONICAL SNOW

THE writer has read with much interest recent articles in SCIENCE, treating of conical snowflakes. Every late autumn and early spring there occurs at Jericho, in northern Vermont, and of course at other similar localities, several falls of such snow, and also an occasional one in winter. It comes only out of cumulo-nimbus clouds, and more commonly when the surface temperature ranges from 34° to 44° F. Conical snowflakes have a granular texture and are built up mainly from countless undercooled cloud droplets that have frozen loosely together. Their greatest diameter ranges from one sixth to one third inch. The writer assumes, from a longtime study of this form of snow, that the nuclei usually, if not invariably, consist of branching tabular crystals.

It is of much interest to consider the conditions within a cumulus cloud that conspire to make the undercooled droplets so arrange themselves upon a tabular snow crystal as to form a granular snow cone. It is certain that, owing to its lightness, a tabular branching snow crystal within a cumulo-nimbus cloud is first wafted upward and about by turbulent air currents. This causes it to become thickly coated on both sides with frozen cloud droplets or granular snow. It now begins to fall with the denser side turned downward, and since it falls faster than the cloud droplets, light granular material then rapidly collects on (is caught by) the under face, thereby destroying the former gravitational equilibrium of the mass and causing it to upset, whereupon the granular snow is caught exclusively, or nearly so, by the new underside, and thus the whole converted into a more or less well-defined double cone with its abutting bases on the opposite sides of the initial tabular crystal. It is conceivable, given a cumulo-nimbus cloud of sufficient thickness, that additional upsettings might occur and thus cause the double cone to become more nearly symmetrical about its basal plane than it otherwise would be.

WILSON A. BENTLEY[1]

JERICHO, VERMONT

RELATIONS BETWEEN FUNDAMENTAL PHYSICAL CONSTANTS

IN an article with the above title, J. E. Mills[1] gives a number of numerical coincidences, such as $(2\pi c)m_0^6 = 10^{-151}$, $(2\pi c)h^{3/2} = 10^{-28}$, $(2\pi c)e^{6/7} = 10^{23/7}$, where c = velocity of light, m_0 = mass of electron, h = Planck's constant, e = electronic charge. Since the numerical values of the constants that he quotes are those suggested by me in 1929[2] I may perhaps be permitted a few words on the subject.

It seems necessary, from time to time, to call attention to the fact that the *numerical* value of any constant, or combination of constants, is entirely arbitrary if the constant, or combination, possesses dimensions. The value in such cases depends directly upon the unit adopted for each dimension. Mills uses values in the C. G. S. system, and these values accordingly depend upon the arbitrarily chosen units of length, mass and time—the cm. gram and second. It is almost inconceivable that there should be an accidental theoretically significant relation between these three units, whose origin is too well known to restate. All the combinations of constants given by Mills have dimensions, and all are equated to 10^n, where n is an integer or fraction.

It is only in the case of dimensionless combinations that the numerical value can have theoretical significance. The two most famous combinations of this character are the fine structure constant α $(= 2\pi e^2/hc)$ and the ratio of the mass of the proton to that of the electron. There are in the literature several articles discussing the possible theoretical significance of these two pure numbers (approximately 1/137 and 1840, respectively). As a much more striking example of the type of numerical coincidence found by Mills, one may quote the known values, mass of electron $= 9.035 \times 10^{-28}$ gram, angular momentum (spin) of electron $= 9.02 \times 10^{-28}$ erg. sec (see, for instance, Pauling and Goudsmit, "Structure of Line Spectra" page 54). But one can not equate grams to erg. sec any more than one can equate horses to oranges—to use a homely but correct analogy.

RAYMOND T. BIRGE

UNIVERSITY OF CALIFORNIA,
MARCH 2, 1932

SPECIAL CORRESPONDENCE

THE PHILADELPHIA INSTITUTE FOR MEDICAL RESEARCH

MEDICAL service is about to receive an important addition through the creation of the Philadelphia Institute for Medical Research. The institute will begin its work next fall. Dr. Leonard G. Rowntree, now director of clinical investigation of the Mayo Clinic, Rochester, Minnesota, and professor of medicine in the University of Minnesota, has been appointed director.

This institute will center its activities in the great Philadelphia General Hospital. Here, in so far as medical research is concerned, it will afford a common meeting place for all medical school services cen-

[1] An obituary note of Mr. Bentley will be found in the present issue of SCIENCE.

[1] SCIENCE, 75: 243, Feb. 26, 1932.
[2] *Physical Review Supplement*, 1, 1, 1929.

tered in the Philadelphia General Hospital. In addition, however, the new institute will hold itself ready to cooperate, aid and foster medical research by collaboration or affiliation with any or all medical and allied institutions desirous of establishing such a relationship.

Why, one may ask, is so much emphasis placed upon the need for medical investigation? Because experience has shown that progress in the past has come largely through this channel and because it is realized that investigation is essential for the better understanding of disease, its prevention and cure and for the better care of the sick. These various considerations constitute the sole object of the Philadelphia Institute for Medical Research.

Research in medicine in the past has come largely through contributions from universities, medical schools, their hospitals and clinics. More recently, because of urgent need, special institutions of research have been created in certain of the great cities in Europe and this country, the best known being the Pasteur Institute in Paris, the Rockefeller Institute for Medical Research in New York City, and one of quite recent date, the Thorndike Laboratory in the Boston City Hospital. All these institutes have made tremendous and permanent contributions to medicine, and added much to the welfare of mankind.

The Philadelphia Institute for Medical Research will occupy a somewhat analogous position to the Thorndike Institute and will concern itself with what is termed clinical investigation, *viz.*, the study of the sick and the diseases from which they suffer. Research will be made for methods of value for the prevention of disease, for improvements in methods of its study, and of diagnosis and treatment of disease, more especially in the earlier stages. Research will be prosecuted also in the fundamental branches of science underlying medical knowledge.

A pioneer feature of this new institute is the attempt to center and foster research through affiliation and collaboration with all medical institutions in Philadelphia, centering its efforts in the Philadelphia General Hospital.

In 1922 a group of Philadelphia physicians, realizing the supreme importance to humanity of research in medicine, arranged a centenary celebration of the birth of Pasteur, which led to the foundation of the Philadelphia Institute for Medical Research, the charter members of which were: Dr. William Duffield Robinson, Admiral William C. Braisted, Dr. Judson Daland, Dr. Frances X. Dercum, Dr. McCluney Radcliffe, Provost Edgar Fahs Smith, Dr. Charles A. E. Codman, Hon. Hampton L. Carson, Joseph Carson, Esq.

In establishing an institution of this kind, it is of the utmost importance to find a man to act as director, possessing the necessary knowledge, enthusiasm, training and proven ability to lead, in all questions concerning medical research. Such a man was found in the senior medical consultant and director of clinical investigation of the Mayo Clinic, Rochester, Minnesota, Dr. Leonard G. Rowntree, who will assume the duties of director at the opening of the institute in the fall of this year.

Plans are under way for the organization of the personnel of the institute.

A site, on the grounds of the Philadelphia General Hospital, has been assigned by the city council for the erection of a new building, at such time as funds become available. In the beginning, however, the institute will occupy temporary quarters in a new building now under construction, at the Philadelphia General Hospital, and will function in conjunction with the staffs of that hospital.

JUDSON DALAND,
President

PHILADELPHIA

QUOTATIONS

ON THE RELATION BETWEEN THE EXPANSION AND THE MEAN DENSITY OF THE UNIVERSE[1]

IN a recent note in the *Göttinger Nachrichten*, Dr. O. Heckmann has pointed out that the non-static solutions of the field equations of the general theory of relativity with constant density do not necessarily imply a positive curvature of three-dimensional space, but that this curvature may also be negative or zero.

There is no direct observational evidence for the curvature, the only directly observed data being the mean density and the expansion, which latter proves that the actual universe corresponds to the non-statical case. It is therefore clear that from the direct data of observation we can derive neither the sign nor the value of the curvature, and the question arises whether it is possible to represent the observed facts without introducing a curvature at all.

Historically the term containing the "cosmological constant" λ was introduced into the field equations in order to enable us to account theoretically for the existence of a finite mean density in a static universe.

[1] Article by Professors A. Einstein and W. de Sitter in the *Proceedings* of the National Academy of Sciences for March. Communicated by the Mount Wilson Observatory, January 25, 1932.

now appears that in the dynamical case this end n be reached without the introduction of λ.

If we suppose the curvature to be zero, the line-elent is

$$ds^2 = -R^2(dx^2 + dy^2 + dz^2) + c^2dt^2, \quad (1)$$

here R is a function of t only, and c is the velocity light. If, for the sake of simplicity, we neglect the ressure p,[2] the field equations without λ lead to two ifferential equations, of which we need only one, hich in the case of zero curvature reduces to:

$$\frac{1}{R^2}\left(\frac{dR}{cdt}\right)^2 = \frac{1}{3}\kappa\rho. \quad (2)$$

The observations give the coefficient of expansion nd the mean density:

$$\frac{1}{R}\frac{dR}{cdt} = h = \frac{1}{R_B}; \quad \rho = \frac{2}{\kappa R^2_A}.$$

Therefore we have, from (2), the theoretical relation

$$h^2 = \frac{1}{3}\kappa\rho \quad (3)$$

$$\frac{R^2_A}{R^2_B} = \frac{2}{3} \quad (3')$$

Taking for the coefficient of expansion

$$h = 500 \text{ km./sec. per } 10^6 \text{ parsecs}, \quad (4)$$

or

$$R_B = 2 \times 10^{27} \text{ cm.},$$

we find

$$R_A = 1.63 \times 10^{27} \text{ cm.},$$

or

$$\rho = 4 \times 10^{-28} \text{ gr. cm.}^{-3}, \quad (5)$$

which happens to coincide exactly with the upper limit for the density adopted by one of us.[3]

The determination of the coefficient of expansion h depends on the measured red-shifts, which do not introduce any appreciable uncertainty, and the distances of the extra-galactic nebulae, which are still very uncertain. The density depends on the assumed masses of these nebulae and on the scale of distance, and involves, moreover, the assumption that all the material mass in the universe is concentrated in the nebulae. It does not seem probable that this latter assumption will introduce any appreciable factor of uncertainty. Admitting it, the ratio h^2/ρ, or R^2_A/R^2_B, as derived from observations, becomes proportional to Δ/M, Δ being the side of a cube containing on the average one nebula, and M the average mass of the nebulae. The values adopted above would correspond to $\Delta = 10^6$ light years, $M = 2.10^{11}\odot$, which is about Dr. Oort's estimate of the mass of our own galactic system. Although, therefore, the density (5) corresponding to the assumption of zero curvature and to the coefficient of expansion (4) may perhaps be on the high side, it certainly is of the correct order of magnitude, and we must conclude that at the present time it is possible to represent the facts without assuming a curvature of three-dimensional space. The curvature is, however, essentially determinable, and an increase in the precision of the data derived from observations will enable us in the future to fix its sign and to determine its value.

REPORTS

SCIENCE ESSAYS BY HIGH SCHOOL PUPILS[1]

FINANCING THE VENTURE

THERE is a committee of the American Association for the Advancement of Science on the Place of Science in Education. One of the pieces of work in which this committee has engaged related to cooperation with teachers, pupils and librarians in secondary schools. In order to carry out the proposed venture special funds were necessary. Funds were secured as follows:

Commonwealth Fund, balance remaining from a previous grant	$ 417.48
American Association Executive Committee	500.00
Harry S. Bowers	1,200.00
Newcomb Cleveland	1,200.00
John W. Harris and John W. Hegeman	1,200.00
A. Cressy Morrison	600.00
Interest on funds in hand	273.53
Total	$5,391.01

All the clerical service was done in the office of the chairman of the Committee on the Place of Science in Education. The council of the American Association for the Advancement of Science has expressed its appreciation of the committee's work, and the council, the committee, high-school teachers, pupils

[2] It seems certain that the pressure p in the actual universe is negligible as compared with the material density ρ. The same reasoning, however, holds good if the pressure is not neglected.

[1] We continue to receive requests from schools wanting a repetition of the cooperative work with the A. A. A. S. Committee. It has not been possible to offer this opportunity again. Furthermore, certain types of unprofitable school contests have led to the conclusion that only those which can be designated as useful should receive encouragement from school authorities. We are entirely in sympathy with that policy.—The Committee on the Place of Science in Education.

[3] *Bull. Astronom. Inst. Netherlands, Haarlem*, 6, 142 (1931).

and librarians appreciate the fine generosity of the individuals who made such substantial contributions to the committee's work. The executive group of the A. A. A. S. Committee consists of J. McK. Cattell, E. R. Downing, I. W. Howerth, B. E. Livingston, Otis W. Caldwell, chairman.

Announcement of Plan

Announcements of the plan were made in educational magazines, and letters regarding it were sent to high-school principals. High-school students were invited to write essays that might possibly be of such quality as to be of interest and value to other students and to the public, or to any one who is interested in the affairs and thought of modern life. It was hoped that the preparation of the essays would be of interest and use to the authors. It was hoped that the effort to prepare superior essays might lead some high-school students to find fields for their own later interests, studies and occupations. It was hoped that an opportunity for attractive and useful juvenile authorship would thus be offered and that the plan would be welcomed by the superior pupils. The best essays would be made the basis of important personal recognitions; also contributions of science books would be made to the libraries of the schools represented by the successful pupils. It was desired to give recognition and encouragement to those young persons who possess unusual interest and capacity for constructive work of high quality.

There were 49 topics announced, upon any one of which work might be done. It was also stated that schools might suggest added topics which could be used if approved by the executive committee. Topics suggested for approval might relate to any science subject or to any applied use of science knowledge or method of work in science. It was thus planned to place before young people the array of modern science, no one science subject being stressed at the expense of any other. It was science, not the sciences, and the appeal of science's ways of working which were placed before the secondary schools. Obviously the committee accepted much more difficult tasks than are involved when a single topic or a few topics in one science subject are offered for competitive essays.

Ways of Working

One pupil might work alone, or a group might cooperate in production of an essay. Advice might be sought from teachers of science, of history, of English, or from the librarian. Books, magazines and personal experiments could be used. The plan of work was reported to the committee chairman. Then, when the pupils registered their intention of entering the competition, when the essay was finally submitted, the administrative head of each school concerned was asked to submit a signed statement as to the persons and methods used in producing the essay. It was therefore hoped to encourage rather than discourage pupil cooperation in prolonged and earnest intellectual effort. It is regarded as entirely honorable for two or more pupils to work together in scholarly effort, rather than to pretend that intellectual production must be wholly individual. Entire frankness as to how work was accomplished was urged. No case was reported in which objection was caused by this procedure.

Benefits Possible to Competing Pupils

The satisfactions and encouragement resulting from worthy achievements must be noted as the chief outcomes from preparation of good pieces of work. Then, each of the twenty winning essays won for the school represented a sum of money ranging from $200 to $50 from which to purchase science books for the school's library. These books carry the names of the winning pupils as the persons whose efforts secured the books for future use in the school. Each winning pupil has received a set of the Wells and Huxley's two volumes entitled "The Science of Life." Also each pupil has received a page of autographs of past presidents of the A. A. A. S. This may be inserted in the pupil's prize volumes, or kept by him in some other way, and may possibly become one of his most valued possessions. These pages now carry 11 signatures of presidents of the A. A. A. S. Above all, the pupil through his own directed intellectual efforts may place himself in line for continued growth in scientific interests.

Judging the Essays

How may essays be judged when written in different ways either by individuals or by groups? Many contests have been judged subjectively or superficially, and the A. A. A. S. Committee desired to contribute to improvement in this matter. An unusually competent judging committee was secured to develop a special technique for handling this task. This committee consisted of Dr. G. M. Ruch, University of California, *chairman;* Dr. M. F. Carpenter, University of Iowa; Miss Claudia Crumpton, Detroit High Schools; Mr. N. B. Hammond, Yonkers High Schools; Dr. F. G. Lyman, University of Chicago; Dr. P. M. Symonds, Columbia University, and Miss Lucy Terrell, Cleveland High Schools. No member of the A. A. A. S. Committee on the Place of Science in Education judged any of the essays. The essays were numbered, the author's names being removed. The judging committee's well-organized scheme included

the various points of merit or demerit, and assigned numerical values to each element. It is hoped that the scheme for judging will be published as a separate magazine article. After the plan of judging had been developed, two well-trained teachers, one in science and another in English, were employed to make independent studies of all the essays, and to score each essay according to the points agreed upon. Each one of these teachers made detailed record of the numerical score of each essay upon each point of the judging scheme. Finally each teacher-reader summed up his ratings for each essay, then arranged all the essays in order of their rank according to their numerical scores. The essays were then divided into five groups according to their scores. Then a full set of copies of all essays that received scores placing them in the first, second or third groups was sent to each of the seven members of the judging committee. Each member made his independent scoring and mailed his report to the chairman. These scores were combined. The resulting rankings determined the 20 ranking essays. It is thought that such a system of judging does much to eliminate any objectionable features of such contests, and increases confidence that science essays may be judged more accurately than is common, almost scientifically.

The Winning Essays

A boy and girl cooperated in more than a year's experimental work, library study and consultation with adults, and produced the highest ranking essay entitled "Rats *vs.* Polyneuritis." Another boy, working alone, won second place with the topic, "My Scientific Experiments—Why I Made Them—What I Gained from Them," and in doing so made for himself and for many others an interesting record of some things that one may do with intellectual profit. Another boy wrote on "The Importance of Protozoa and My Observations of Them," and his essay tied for third place with one entitled "Crystals and Crystallization," which was done by seven pupils who cooperated with their pupil chairman in their chemistry class in the production of their essay. The fifth essay was upon "The Water Supplies of Ancient and Modern Peoples." Other winning topics are: "My Experiments with Hydra"; "A Home in Crude Petroleum"; "The Life and Inventions of Thomas A. Edison"; "The Study of Rats and Mice"; "What Modern Science Means to Me and My Community"; "How Science has Helped Man Overcome his Limitations"; "A Hero of Science—Dr. Jacques Loeb"; "Inventions in Astronomy"; "How has Science Changed my Daily Life?"; "The Relation of Science to the Art of Music"; "Rayon"; "Science and the Home"; "Cellulose and Rayon"; "Products of the Electric Furnace"; "Radium and its Uses." These and many other topics which were submitted prove a wide range of genuine interest in scientific studies. Seventeen states were represented in the whole list of essays submitted, and ten states were represented in the twenty winning essays.

Some mature scientists may argue that secondary school pupils can not deal with topics such as those selected. It is true that some of the winning essays are not highly valuable, though some are quite remarkable in their fine quality. Good essays were desired and some good ones were secured. May I merely comment that during a meeting of the American Association, some papers are presented which do not meet with strong approval by those who hear them, and there have been times when a careful search had to be made to discover productions worthy of the association's annual prize.

Library Reports

Before a school's library could actually secure the funds for purchase of books, the school was asked to send the committee a report on the science books already in the library, what their library needs seem to be, and what they wish to do with the funds when secured. The Enoch Pratt Free Library of Baltimore had prepared an excellent list of science books which the committee sent to each winning library. These library reports are all now in hand except one, and will be published separately.

Science can help itself and its devotees by giving more attention to its recruits at the lower levels. The cooperative essay contest is but one of several ways of making early discovery and giving needed guidance to young persons of unusual capacities and interests.

A List of the Winning Pupils, Their Topics and the Schools Represented by Them

Rank	Student	School
	Group I	
1.	Jane B. Sill Edward H. Reisner *Topic: Rats vs. Polyneuritis*	The Lincoln School of Teachers College, New York City
	Group II	
2.	Daniel Eisler *Topic: My Scientific Experiments—Why I Made Them—What I Gained from Them*	Glenville High School, Cleveland, Ohio
3.	Ralph Lawrence *Topic: The Importance of the Protozoa and My Observations of Them*	The Lewis & Clark High School, Spokane, Washington
3.	Lincoln School Chemistry Class Winston Hurd, *chairman*, Ernest Landsteiner,	The Lincoln School of Teachers College, New York City

Frederick Forsch, Kim Plockman, John Steinman, Eugene Williams, Jane Winternitz
Topic: Crystals and Crystallization

GROUP III

5. Byrne C. Manson — John Muir Tech. High School, Pasadena, California:
Topic: The Water Supplies of Ancient and Modern Peoples
6. Dunbar Triplett, Jr. — The Lewis and Clark High School, Spokane, Washington
Topic: My Experiments with the Hydra
7. Wm. Stewart — Beverly Hills High School, Beverly Hills, California
Topic: A Home in Crude Petroleum
8. Katharine Marie Hall — University High School, Ann Arbor, Michigan
Topic: The Life and Inventions of Thomas Alva Edison

GROUP IV

9. John Winslow French — Pawling, New York
Topic: The Study of Rats and Mice
10. Virgil Bolen — Academy of the Western Illinois State Teachers College, Macomb, Ill.
Topic: What Modern Science Means to Me and My Community
11. Rose Auerbach — Washington Irving High School New York City
Topic: How Science has Helped Man Overcome His Limitations
12. Robert Ray — University High School, Oakland, California
Topic: A Hero of Science—Dr. Jacques Loeb
13. David Putnam — High School, Keene, N. H.
Topic: Inventions in Astronomy
14. Jean Elizabeth Boling — Shortridge High School, Indianapolis, Ind.
Topic: How has Science Changed my Daily Life?

GROUP V

15. Matillda Diorio — S. Phila. High School for Girls, Phila., Pa.
Topic: The Relation of Science to the Art of Music
16. John Alloways — Central High School, Kalamazoo, Michigan
Topic: Rayon
17. Freda Becker — S. Phila. High School for Girls, Phila., Pa.
Topic: Science and the Home
18. Omer Widmoyer — Central High School, Kalamazoo, Michigan
Topic: Cellulose and Rayon
19. Wade Allen — Central High School, Kalamazoo, Michigan
Topic: Products of the Electric Furnace
20. Benjamin Richman — Lyndhurst High School, Lyndhurst, N. J.
Topic: Radium and its Uses

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SCIENTIFIC APPARATUS AND LABORATORY METHODS

A RAPID METHOD FOR OBTAINING SINGLE SPORE CULTURES OF MOLDS

IN the course of a cultural study of a large number of molds it became desirable to procure as rapidly as possible single spore cultures of certain of the hardy, saprophytic molds.

With a modified Chambers micromanipulator[1] a comparatively large number of ascospores of *Aspergillus fischeri* were individually isolated on drops of malt extract agar[2] made on sterile cover slips. The mode of isolation in brief is as follows. A standard research microscope with mechanical stage is mounted on a metal base. To this base, properly aligned, are attached in front of the microscope movable, vertical arms designed to hold the micropipettes with which spore isolation is accomplished. These arms have vertical and lateral fine adjustments, enabling the operator to manipulate the pipettes as desired. The pipettes are made up just before use by drawing out sterile 3 mm glass tubing to the desired fineness in a micro-flame. The extreme tips of the pipettes are bent at right angles to the rest of the shaft. A moist chamber with an aperture on its upper side is placed in the mechanical stage. Two sterilized square cover slips are fitted with edges together over the open top of the moist chamber. On the under side of one cover slip has been placed a drop of sterile agar medium, on the other, a drop of spore suspension. The pipettes, as they are made up, are clamped in the arms in a horizontal position, and their vertical tips are then, by means of the movable pipette arms, brought into the moist chamber and centered under the low power objective. By means of the vertical

[1] For details as to the use of this micropipette method in the isolation of single cells, see W. H. Wright and E. F. McCoy, "An Accessory to the Chambers Apparatus for the Isolation of Single Bacterial Cells," *Jour. Lab. and Clin. Med.*, 12, 795, 1927.

[2] The nutrient agar used was made up on the basis of 25 g malt extract (Trommer's Analyzed), 15 g agar, 1,000 cc distilled water. The malt broth was made with 25 g malt extract, 1,000 cc water. These media were filtered through asbestos for clarification, but a clear agar is scarcely necessary when germinated spores are picked, as their development may be readily followed on the hanging drop slide.

fine adjustment one of the pipettes is then brought momentarily into the drop of spore suspension and a considerable amount of the liquid with its spore load is taken into the pipette by capillary action. With the mechanical stage the chamber is moved to a clear spot on the cover slip, and a certain amount of liquid expelled, by means of a long blowing tube, to form a small drop on the cover slip. This procedure is continued until a drop is obtained which contains a single spore. The second pipette is then brought into this drop and the spore removed. The drop of sterile agar medium is brought into position and the isolated spore deposited on it. As the spores are isolated, the cover slips with the agar drop and its single spore are sealed with sterile vaseline onto deep hanging drop slides, the well of the slide containing sufficient moisture to prevent drying of the agar, and the whole is incubated at the desired temperature.

Early results were most discouraging, as none of the single spores germinated. It was deemed advisable to germinate the spores in malt extract broth, and to isolate germinated spores shortly after the emission of the germ tube, in the hope that growth, once started, would be continued. That the procedure may be successfully applied, at least to some of the common, vigorous forms, is indicated in the accompanying table.

An experienced operator can, with considerable ease and with absolute certainty, isolate 20 or more germinated spores in the course of from three to five hours with the use of this micromanipulator method, so that it is apparent that single spore cultures of many organisms can be accumulated with considerable rapidity.

GROWTH OF SINGLE GERMINATED SPORES

Organism	Germinated spores isolated	Spores continuing growth	Per cent. continuing growth
(Ascospores)			
Aspergillus fischeri	8	5	62
(Conidia)			
Aspergillus fischeri	17	10	59
(Conidia)			
Aspergillus nidulans	8	3	37
Aspergillus sydowi	12	6	50
Botrytis sp.	8	7	87
Hormodendron sp.	12	12	100
Monilia sitophila	8	8	100
Penicillium digitatum	12	3	25
Penicillium islandicum	8	7	87
Syncephalastrum sp.	11	8	73
Trichoderma sp.	9	5	55
Totals	113	74	Av. per cent. = 65

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A METHOD FOR DETERMINING THE VOLUME OF SMALL PIECES OF TISSUE

A SERIES of test-tubes of varying sizes have each a capillary tube drawn off from one side, as shown in Fig. A. With the tube retained in a perpendicular position fluid is run into the tube to a point above the lower outlet and then brought down to this exact level by air pressure exerted through the mouth of the tube. For greatest simplicity direct mouth pressure has satisfactorily served this purpose.

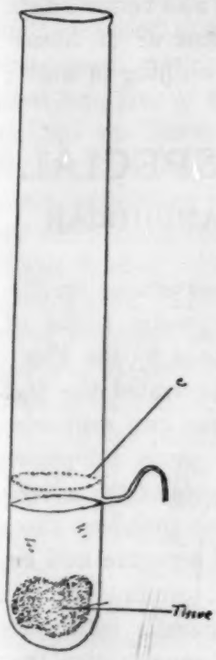

Fig. A

The tissue is then immersed in the fluid, and in accordance with the principle of fluid displacement, a new level is established at "C." By a procedure similar to that described above, the displaced fluid is collected through the capillary tube and its volume estimated.

Temperature and barometric corrections are hardly necessary, since in volumes as small as can be measured by this method the errors are negligible.

By this method volumes as small as one tenth of a cubic centimeter have with ease been estimated. It is, however, essential to use a test-tube whose diameter is only slightly larger than that of the tissue in order to secure a maximal rise of fluid and minimize error.

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ALOXITE AS AN ABRASIVE FOR GRINDING BONE SECTIONS FOR HISTOLOGICAL PURPOSES

SECTIONS of dry bone for histological study are prepared usually by one of the following methods: Grinding on a lathe, on compact pumice stone, on sand—or carborundum—paper of different grades of fineness, and lastly, on or between stones of suitable fineness. These methods are suitable but slow and tedious.

In the course of preparation of bone sections, the writer has found that aloxite powder (crystalline alumina) possesses exceptional abrasive properties for rapidly reducing bone to any desired thinness.

The technique here given has been found most satisfactory and particularly suitable for classroom use be-

cause the student can grind sections for himself quickly and inexpensively. Thin sections of about 1 mm in thickness are sawed with a hack saw and given to the students who grind them on glass plates (discarded lantern slides make suitable plates) with aloxite powder and water. The quantity of water used is just enough to maintain the powder in a pasty consistency during the grinding. Ordinary corks are used to hold the sections during the process. The grinding should be conducted by frequently alternating the surfaces, thus insuring more uniform thinness and better finish. When the sections become transparent or of tissue-paper thinness, they are polished by dipping in water, blotting dry and rubbing carefully with finger on a carborundum or greenstone hone. This last step is necessary so as to fill the lacunae and canaliculi with débris. The sections are mounted, as usual, in gelatin.

Comparative trials show that aloxite used as described cuts twice as fast as the fastest of the other above-mentioned abrasives. No more than ten minutes should be required to completely grind and mount a section.

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SPECIAL ARTICLES

THE CENTRIOLE OF THE AMPHIBIAN LEUCOCYTE

IN 1926 Belar published his observations on the centrioles of the perihepatic leucopoietic tissue of Salamandra. These studies were made by the Flemming-hematoxylin method and demonstrated the fact that a cell in the interphase contains two centrioles which have been derived directly from telophasic division of a single centriole at the pole of the mitotic spindle and that during a subsequent prophase these two centers of the non-dividing cell separate and become located at the poles of the spindle. Belar's series of figures illustrating this genetic continuity of the centriole is so completely demonstrative that it is difficult to understand why these very significant results have not received more attention in recent discussions of the central body problem.

I have repeated Belar's observations on Salamandra and have extended the study to other Urodeles, namely: Amphiuma, two species of Amblystoma, Triturus and Siren. Material was fixed in the fluids of Champy, Flemming, Benda, Helly, Bouin, and a saturated solution of corrosive sublimate in normal saline. Staining was by means of iron hematoxylin, Kull's acid fuchsin-thionin-aurantia and Benda's alizarin-crystal violet. The facts are demonstrated by any of these combinations, but the Benda method is most useful, since it stains the centrioles a distinctive color, unlike that of any other structures in the cell.

This extensive reexamination completely confirms Belar's results and in my opinion incontestably establishes the fact that the centrioles maintain direct visible genetic continuity through all the numerous cell generations in the differentiation of the mature leucocytes. This general conclusion holds for the six types examined, but in minor details there are differences among the genera. The following brief description refers, in all its details, only to Amphiuma.

The myelocyte in the interphase contains a single large aster. The Golgi apparatus is closely applied to this structure, and chondrioconts in its vicinity are oriented so that their axes are radial to its center. At the focal point of the astral rays is a spherical zone that stains considerably more heavily than the general cytoplasm, and which I shall more or less arbitrarily call the centrosome. Outside this zone and considerably excentric with reference to the focal point of the astral radiations are two granules which stain very intensely and which I consider are most accurately termed the centrioles. These have so great an affinity for hematoxylin, acid fuchsin or crystal violet that slides can be extracted until the centrioles are the only stained objects outside the nucleus. Both centrosome and centrioles are well preserved and may be stained after such fixatives as Champy's fluid, which preserves not the least trace of an aster. In early prophase the centrioles seem to enlarge slightly and then they move apart. A spindle forms between them, and upon breakdown of the nuclear membrane the chromosomes become arranged in the metaphase plate. The centriole at this stage is exactly at the focal point of the spindle fibers, but I wish to forestall any possibility of a suggestion that it is their coagulated focal point by stating that in Benda preparations the spindle fibers are light orange, while the centriole is a brilliant purple. The centriole in this material is far more clear-cut and definite than any I have ever seen. Its size and spherical shape are constant. In the early telophase, after disappearance of the polar part of the spindle, the centrosome and astral zones are reformed around the centriole, and in middle telophase it can first be clearly seen that the centriole has divided. At first these division products are very small and close together, but in late telophase they move apart somewhat and enlarge to the size which they maintain throughout the interphase.

The above description is based upon examination certainly hundreds of thousands of leucocytes of mphiuma. The results may seem more convincing to me cytologists when I state that I have found not e cell inconsistent with this outline of the history the centrioles. The only cells in which these facts e not easily observable are those where the staining either so heavy as to obscure all details or so light at there is no differentiation of structures in the toplasm. I have slides, prepared by the Benda ethod, in which the stain has been extracted to such degree that the centrioles are a faint blue and even en it is always possible in every cell to make out ese "ghosts of centrioles" exactly where one would pect to find them. On any properly stained slide ery cell demonstrates the centriole situation to be as have described above.

It is perhaps also worth mentioning that I have served many mitotic figures in the hepatic glandular lls on the same slides with the leucopoietic tissue. e centrioles, always present at the poles of these indles, are identical in size and staining character- ics with those of the leucocytes.

In conclusion let me emphasize the aspects of this e of the leucocyte that make me consider it highly nificant for the whole centriole problem in its esent state. First, it demonstrates the individuality d genetic continuity of the centriole in somatic tis- e of adult animals by the use of a wide variety of hnical methods. The more general significance of is is that the centrioles are the only part of the totic apparatus that persists from one cell genera- n to the next. Second, the centrioles are not the gulated focal point of the spindle fibers, because e histories of these two structures are very different d because there are marked differences in staining ction. Third, the centrioles are not the coagulated al point of the astral rays, since there are differ- es in fixing and staining reactions and especially ause the interphase centrioles are *double* and ced *excentrically* inside a *single* aster.

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EAF TEMPERATURES OF COTTON PLANTS WITH PHYMATOTRICHUM ROOT ROT[1]

THE leaves of cotton plants that have wilted from *ymatotrichum omnivorum* root rot are so regularly d so definitely warmer than those of normal plants t the writers have been able to utilize this difference leaf temperatures in diagnosing cotton plants about to succumb to the effects of the disease.[2] It has therefore been of interest to find the actual differences in temperature between leaves of cotton plants with root rot and those of normal plants. The observations recorded below have been made on plants of Startex cotton (Texas Station No. 7000) growing in experimental plats at College Station, Texas.

MEASUREMENTS WITH MERCURY THERMOMETERS

Two ordinary chemical thermometers, previously tested and found to register the same temperatures and to respond at the same rate to changes within the range used, were mounted inside an insulated cardboard box, free of the sides, and used for simultaneous readings on leaves from root-rot and from normal plants. This box was carried around the field to the plants, care being taken to have the open side of the box away from the sun and the thermometers thus always shaded. The leaves were selected from adjacent plants, similar in size and other characteristics except that one had wilted from root rot while the other was apparently normal; and each of the pair of leaves to be compared was selected of the same size, height on the plants and exposure to the sun. Each leaf was cut off the plant with small scissors, grasped with forceps, doubled together rapidly, and the doubled leaf then folded around the bulb of the corresponding thermometer. An insulating cardboard cover was immediately slipped around the bulb and leaf, and clamped loosely in place. The entire operation took ten seconds or less, and the leaf was touched only with the implements which were all kept in a shaded compartment of the thermometer box when not in use. Immediately before putting the leaves on the thermometers, the air temperature was read and recorded for each thermometer; after clamping the leaves in place, readings were taken at intervals of 1 minute for 3 or 4 minutes. The thermometers usually showed a rapid change during the first 30 seconds, but after 1 minute the equilibria reached usually remained unchanged for 5 to 10 minutes or until the thermometer bulbs were again exposed to the air. The thermometers were alternated, each being used first for the leaf from a normal plant and then for the leaf from a root-rot plant. On account of this alternation, any unobserved lag in reaching equilibrium with air temperature would have tended to decrease rather than to accentuate the differences found between the leaves from the normal plants and those from the wilted plants.

Measurements with mercury thermometers were made on July 15, on a bright, sunny afternoon, and again on July 21, 1930, early on a partly cloudy

[1] Published with the approval of the director of the xas Agricultural Experiment Station as Contribution o. 177, Technical Series, of the station.

[2] J. J. Taubenhaus and Walter N. Ezekiel, "Cotton Root-rot and Its Control," Texas Agr. Exp. Sta. Bul. 423, 1931.

morning. On both occasions, the leaves from normal plants were usually definitely cooler than air temperature, while leaves from the diseased plants were usually as warm as air temperature or slightly warmer. Thus with one pair of leaves, the leaf from the root-rot plant raised the thermometer to 101° F. from an initial air-temperature reading of 100° F., while the leaf from the normal plant lowered the reading to 95° F. Invariably, leaves from the plants with root rot were at least slightly warmer than the corresponding leaves from normal plants. The differences between the temperatures of individual pairs of leaves ranged from 0.5° to 6.0° F. higher for leaves from the plants with root rot than for the corresponding leaves from normal plants. The average difference for 11 pairs of cotton leaves was nearly 3° F. Two pairs of leaves from adjoining normal and root-rot fig trees similarly showed differences of 2.5° and 3° F.

Measurements with Thermocouples

Some thermocouple measurements were made later in the season, using a large portable demonstration galvanometer and a multiple thermocouple outfit (designed for radiation measurements).[3] The sensitive units consisted of two flat plates, each containing 26 antimony-bismuth thermocouples mounted flat on the plates. The larger disks in which the thermocouple plates were set were mounted about 25 mm apart, facing in opposite directions. The entire outfit was taken into the field and used inside a shaded box. Each measurement was made by pressing the selected leaf, folded, against one of the thermocouple plates, using a soft pad to hold it against the entire surface; while the other thermocouple plate was always at air temperature. Deflection of the galvanometer was thus directly proportional to the differences between the leaf temperatures and air temperatures. The sensitivity of the outfit was such that a deflection of one division (nearly 1 cm) on the large scale was equivalent to 2.25° F., and accurate readings could be made to about 0.5° F.

Measurements made on September 15, 1930, with the thermocouples, agreed in general with the previous results. Leaves of the normal cotton plants were generally cooler than air temperature, ranging from 2.5° above air temperature to 4.5° below and for 11 leaves averaging 1.5° F. below air temperature. Leaves from root-rot plants varied from 1.3° below air temperature to 6.5° above, with the average for 24 leaves at 1.2° F. above air temperature. The average difference between temperatures of the leaves from normal and root-rot cotton plants was thus nearly the same as in the July series. Thermometer readings of temperatures of leaves from some of the plants, taken periodically, agreed fairly well with the thermocouple readings.

Increase of temperature of cotton leaves has been shown by Eaton and Belden[4] to be closely correlated with decreases in the transpiration rates; and they note also (p. 11) that increase in temperature of cotton leaves, wilting in this case from a shortage of soil moisture, may become perceptible to the touch several hours to a day in advance of visible wilting of the leaves. There can be no doubt that the heightened temperatures of the leaves of plants with Phymatotrichum root rot are similarly due to the decrease in water supply, which agrees with the usual conception of the immediate cause of death of plants from this disease. The assumption is that plants succumb as the result of mechanical interruption of the transpiration stream by the rotting of the roots. The breakage of the flow of water, often just below the surface of the ground, is so marked that we have frequently observed, around the base of freshly-wilted cotton plants, the exudation of water in amounts sufficient to wet the soil around the plants, this exudation from the injured portions of the roots presumably being induced by the continued pressure from the uninjured portions of the roots below the area involved by the disease.

Summary

Leaves from plants wilted from Phymatotrichum root rot were as much as 6.5° F. warmer than air temperature, while leaves from normal plants were usually cooler than air temperature. Series of measurements made with mercury thermometers and thermocouples showed that in July and in September, 1930, leaves from root-rot cotton plants averaged about 3° F. warmer than leaves from normal plants.

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[3] This equipment was made available through the courtesy of Dr. O. W. Silvey, head of physics department, A. and M. College of Texas.

[4] Frank M. Eaton and Galen O. Belden, "Leaf Temperatures of Cotton and Their Relation to Transpiration, Varietal Differences, and Yield," U. S. Dept. Agr. Tech. Bul. 91, 1929.

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